Schafer

Space Object Identification (SOI)

February 1999

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Task Report - Naval Research Laboratory
Contract N00014-97-D-2014/001

SPACE OBJECT IDENTIFICATION

Introduction

This final report documents the activities and deliverables completed for the Space Object Identification Task for the Naval Research Laboratory (NRL) during its performance period covering 1 February 1998 through 31 January 1999.

The source funding for this task was Air Force Research Laboratory/Surveillance Technologies Division (AFRL/DEBS).

The objective of this task, titled "Space Object Identification (SOI) ," is to support AFRL technology development in electro-optics sensors, algorithms, and processing for SOI. The background for performing this task is as follows; The United States Space Command (USSPACECOM) has the mission to develop and maintain the Space Order of Battle (SOB)/Space Situational Awareness (SSA). This includes the knowledge of where all man-made objects in space are, what they are, what their missions and capabilities are, and what their current status is.

This is supported by all source intelligence, which includes SOI techniques and processes. SOI provides data that can help determine status, mission and capabilities. The SOI data products include radar, optical signatures, and imagery, e.g., Haystack radar images, Maui optical imagery, and Maui photometric signatures.

Task Approach

The approach for this task was to review in depth the requirements and USSPACECOM Long Range Plan to determine top-priority needs. Needs that related to SOI included identification and status determination of deep space (DS) objects. Key technologies that could make a difference were identified. These included spectral photometry and active imaging from the ground. The approaches on how to develop the technologies were established. For spectral photometry, this included developing models, predicting hyperspectral signatures from NAIC models, comparing the models with actual measurements, and developing the algorithms.

To further understand how SOI and Space Surveillance, in general, support the warfighter, analysis was to be completed using existing requirements documents, mission area plans, strategic plans, and other related reports. The result of the analysis were to be documented in a Space Situational Awareness briefing, to include Recognized Space Picture to support JFC Common Operating Picture (COP), as well as reflecting commercial needs.

Completed Activities and Deliverables

Schafer personnel attended the April 1998 Space Control Conference sponsored jointly by AFRL and MIT/Lincoln Laboratory (MIT/LL). This conference provides an overview by many government and contractor organizations of the work they have accomplished over the previous year, primarily in space surveillance. It encompasses both radar and electro-optical surveillance capabilities and sensors. Schafer presented a paper on the use of electro-optical sensors for a space-based observation network for space surveillance.

AFRL/DEB, also gave a briefing on "Space Situational Awareness", developed by Schafer (Att. 1).

During June 1998, Schafer provided extensive support in the space surveillance arena to the 1998 Air Force Scientific Advisory Board (SAB) Space Control Study. Schafer participated in the review of NRO space surveillance requirements on 1-2 June and as a result prepared recommendations for consideration by the SAB. Schafer also participated in the two-week summer study on the same topic in Newport Beach, California. Schafer helped review the needs and the requirements for both the military and commercial space industry for support from the Air Force Space Surveillance Network. Schafer developed specific technical and programmatic recommendations for the upgrades of this network. These needs addressed moving space surveillance to space, upgrades to selected ground-based radars, and improvements in the radar/optical sensors that provide imagery and signatures that are used to identify and characterize space objects. The SAB will review these recommendations and brief them to the senior leaders of the Air Force later this year.

In July 1998 Schafer updated the "Space Situational Awareness" briefing (Att. 2) to include radar as well as electro-optical solutions to the AFSPC deficiencies. It is planned that this briefing will be presented to the senior officers at AFSPC and USSPACECOM. It includes the results of many detailed Schafer analyses that drive the needs for future electro-optical sensors.

At the request of AFRL/DEBS, Schafer personnel traveled to Peterson Air Force Base, Colorado, in September 1998 to brief the new AFSPC Space Surveillance Requirements branch chief. The briefing topics were "Space Situational Awareness" and "Space Observation Network Study." Some revision and updating of existing briefings was accomplished prior to the trip.

In October 1998, also at the request of AFRL/DEBS, Schafer personnel developed briefings and short technical reports addressing the operational utility of Laser Radars. The briefings included "HI-CLASS Utility Study Approach" (Att. 3) and "Laser Radar (LADAR) Concept and Operational Utility" (Att. 4). The "Space Surveillance Requirements" report (Att. 5) summarized the current metrics and SOI user requirements, particularly the high accuracy ones that a LADAR system can support. The "List of Logistics/Normalization Deliveries" report (Att. 6) described hardware, software, operations, training, logistics, and environmental items required of a developing system prior to operational use.

Schafer developed a briefing on "Color Photometry of Geosynchronous (GEO) Satellites," as part of the AFRL/DEBS Signature Program (Att. 7). Schafer presented this briefing on 10 November 98 in Colorado Springs to AFSPC, Space Warfare Center Space Battlelab (SWC/SB), and USSPACECOM representatives. A detailed trip report was also delivered to AFRL/DEBS, DEPA, and DEBI (Att. 8). On 19 and 23 November 1998, Schafer then supported several follow-on meetings to discuss this technique and the SWC/SB SOI In Living Color (SILC) initiative. Schafer documented and delivered to AFRL/DEBS and AFSPC the color photometry observing procedures (Att. 9).

On 17, 19, and 30 November 1998, Schafer supported several Maui Integrated Products Team (IPT) meetings on the strategic planning of the site's electro-optical and laser

technologies and systems.

As part of the AFRL/DEBS Signature Program, in December 1998 Schafer completed an analysis on the projected user requirements (Att. 10) and deliverables to transition a R&D Color Photometry Data Exploitation Tool to operational use (Att. 11). In conjunction, Schafer started the development of a roadmap that listed the R&D milestones and activities to complete a prototype tool that determine the identification of Geosynchronous (GEO) satellites using color photometry.

After several revisions, Schafer completed and delivered, in December 1998, the condensed and executive summary versions of the "Space Situational Awareness" briefing (Att.s 12 and 13). Schafer provided technical support on developing an approach for the AFRL optical assets providing satellite diagnostic imaging for commercial entities.

Schafer provided technical support at the Space Surveillance-related meetings of the Space Control TPIPT, held 28-29 January 1999. Schafer provided information on several AFRL/DEB projects such as color photometry, LADAR systems, Maui electro-optical and laser systems.

Space Situational Awareness

Essential

for

Military

Operations

Background

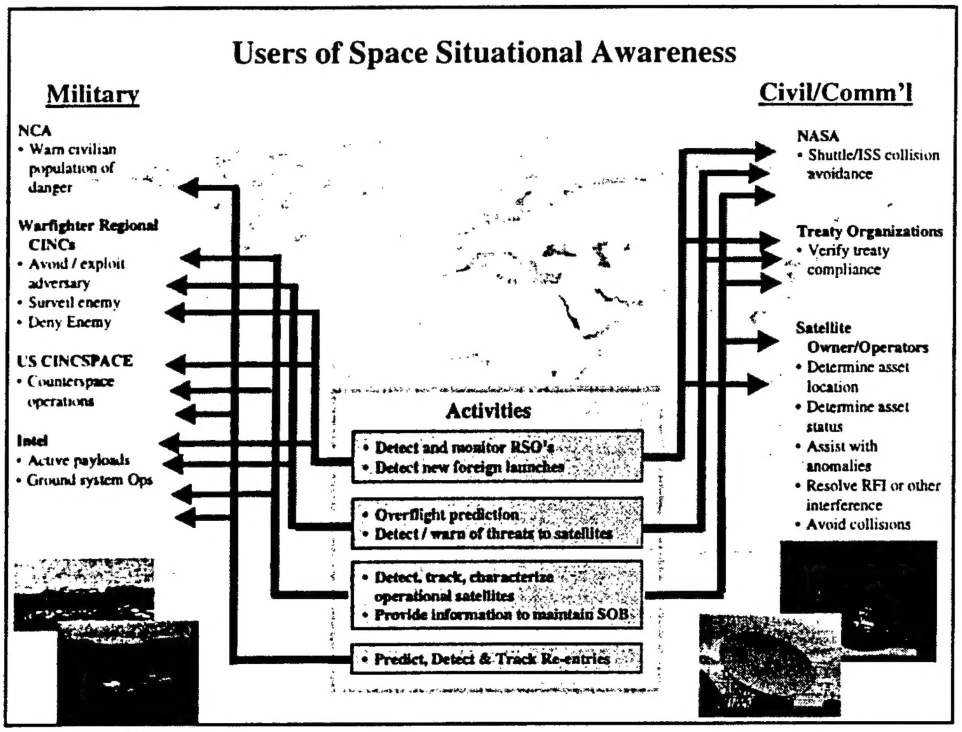
Military use of all classes of space systems is increasing
- US/Allied
- Potential Adversary

U.S. economic interests in space growing rapidly

Infrastructure for maintaining control of space is shrinking

Strong Leadership Support of Space Situational Awareness by:
- National Space Policy
  - "Modernize Space Surveillance..to detect...characterize threat to US space systems...and protection of military activities
- USCINCSPACE
  - "Space surveillance is the 'first order of business' at USSPACECOM"

Space Situational Awareness Modernization Needed



Warfighters Must Have Situational Awareness
Source Comparison

SA Information	Terrestrial Forces Sources for SA	Space Forces Sources for SA
Threat/target locations, motion, IFF Traffic control Order of battle	AWACS	SSN
Mobile threats/targets Fixed targets	JSTARS	SSN
Threat/target locations and operations from RF intercept	Rivet Joint	National Systems
Target/threat locations and characteristics	National systems	SSN National systems
BM/C^4I	AOC/JIC	CMOC/CIC

You wouldn't go to war w/o AWACS ...

Space Situational Awareness Essential to Terrestrial Military Operations

OVERFLIGHT WARNING

- Potential threats to our terrestrial forces and operations
- Timing of overflight
- Capabilities of ISR systems
- Negation of these threats when necessary

THREAT WARNING

- Potential threats to our space assets that support terrestrial SA and Intell Prep of the Battlefield
- Timing of threat
- Threat characteristics
- Origin of threat

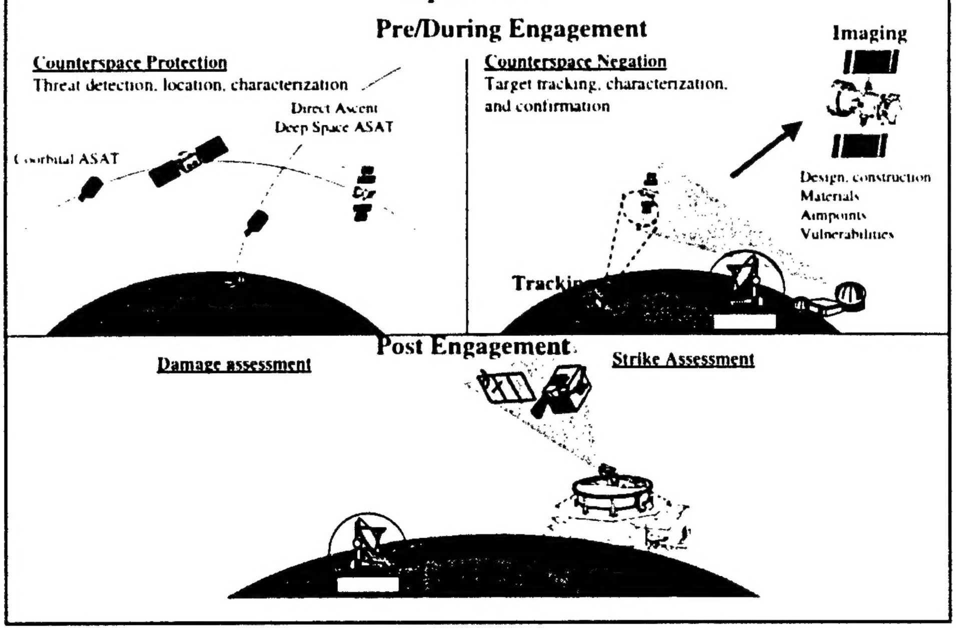
EXPLOITATION

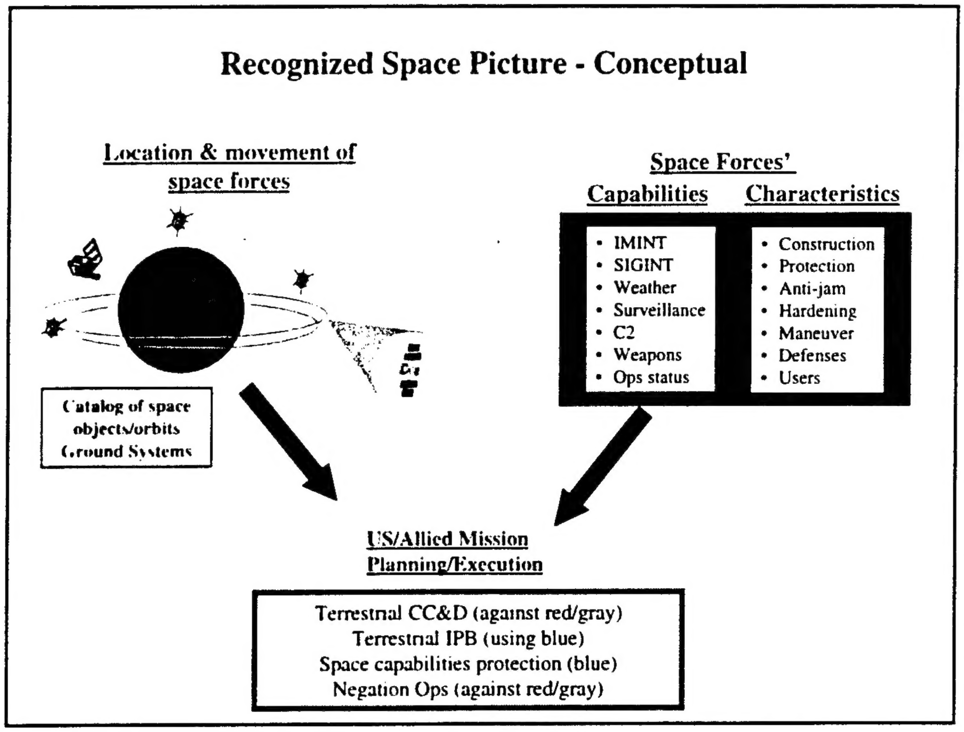
- Space C^2 capabilities and activities used by our adversaries
- Assist intell collection

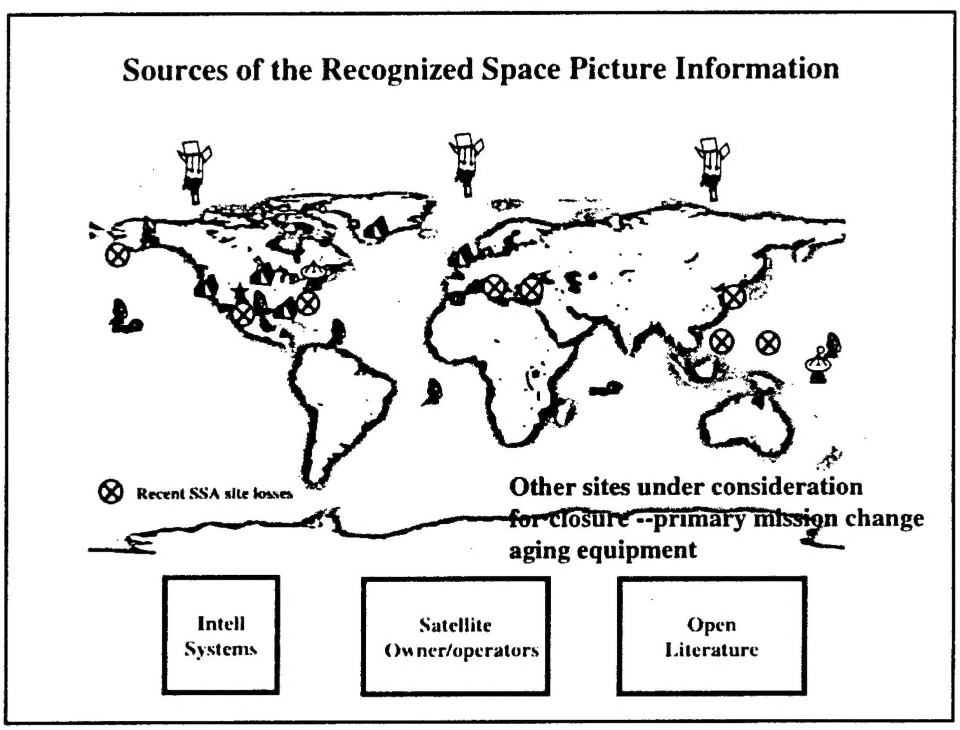
ANOMALY RESOLUTION & DAMAGE ASSESSMENT

- Blue space systems used by US Military
- Assist routine anomaly resolution
- Assist damage assessment from natural and adversary causes

Space Situational Awareness Essential to Counterspace Operations




Recognized Space Picture - Conceptual
Location & movement of space forces
Catalog of space objects/orbits Ground Systems
Space Forces'
Capabilities
• IMINT
• SIGINT
• Weather
• Surveillance
• C2
• Weapons
• Ops status
Characteristics
• Construction
• Protection
• Anti-jam
• Hardening
• Maneuver
• Defenses
• Users
US/Allied Mission Planning/Execution
Terrestrial CC&D (against red/gray)
Terrestrial IPB (using blue)
Space capabilities protection (blue)
Negation Ops (against red/gray)


Sources of the Recognized Space Picture Information
Recent SSA site losses
Other sites under consideration for closure --primary mission change aging equipment
Intell Systems
Satellite Owner/operators
Open Literature

Transition to describing how the space satellite population is evolving vis a vis the needed recognized space picture-- I.e. where are we headed in the future

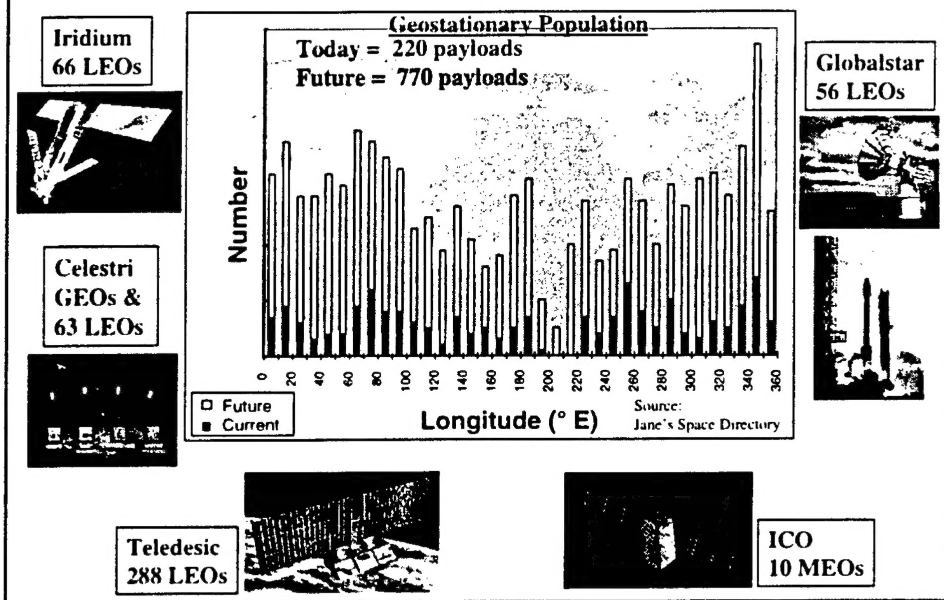
The environment
- Growing space population
- Reduced ability to know the characteristics, capabilities and ops status
- Commercial & dual use of commercial
- Small objects/manned presence

The force structure

Challenges to Maintaining the Recognized Space Picture

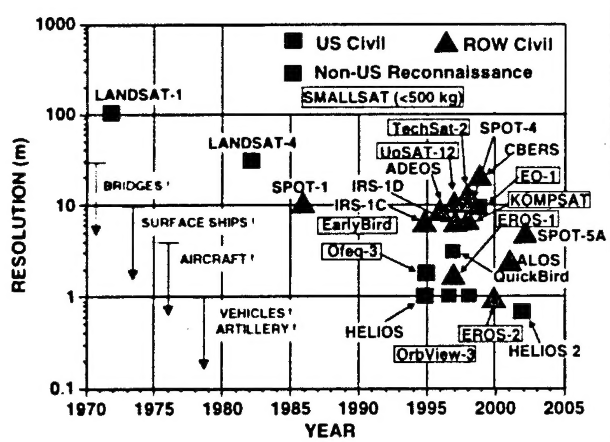
- Growth in numbers of space objects
- Increased complexity of space payloads
- Military use of commercial space capabilities--Owned/leased
- Reduced ability to determine the characteristics, capabilities and ops status
- Small objects and manned presence in space
- Shrinking force structure

Growing Space Object Population



Growing Complexity of Active Payload Operations and difficulty of identifying them, in a timely manner

- Multiple, independently directed, narrow comm beams
- Ability to image far from the nadir ground direction
- Orbit adjustments and maneuver
- Growth in number and capability of foreign and commercial ISR systems
  - Optical, radar sigint, elint
- Proliferating number of launch sites/platforms
  - Air launches
  - Sea launches



Space Intelligence Needs & Source Limitations

Space Control Needs

ID
Class and type

Status
Is it operational?

Characterization
Primary/secondary missions
Changes
Detailed characteristics

Information more difficult to obtain

Past → **Future**

SIGINT → $\boxed{\text{encryption}}$ - - - →

Launch Vehicle Typing — Unique → 1, 2, 3 → General Purpose 1, 2, 3

- **Anomalous behavior appears to be more frequent**
  - **ADEOS**
  - **Earthwatch**
  - **Classified examples**
- **MASINT and imaging techniques have not kept pace**

Space Situational Awareness Provides Critical Support to US Economic Interests in Space

Integrated Space "Traffic Control" and "Accident Investigation"

CINC Vision--global partnerships
military use of huge commercial investment
Analogy with protection of the sea lanes of comm--space lanes in the future

Identification of safe launch corridors

Detection and location of potential conjunctions of space objects

Support to anomaly resolution and post mortem assessments

US has ____ investment in space

GPS began as a ~~military system~~ and now is a ~~national resource~~

The SSN is a national ~~resource~~ that needs upgrading to support ~~all US space~~ activities

Site Closure - future

Aging Equipment chart

Many Recent Failures in Space Situational Awareness

SPACE NEWS July 96

Space Debris Damages French Defense Satellite

By LEONARD DAVID
Space News Correspondent

The Boston Globe

MISSILE DESTRUCTION RAISES FEARS OF SPACE DEBRIS

SOURCE: By David L. Chandler, Globe Staff

A Minuteman missile on a test flight over the Pacific Ocean last month was probably destroyed in a collision with a piece of space junk, aerospace analysts and spokesmen said yesterday.

Multiple Classified Examples

SPACE NEWS Aug 97

European, Russian Satellites Have Close Call in Orbit

By PETER B. de SELDING
Space News Staff Writer

The Washington Post

Nov 96

Craft? What Craft? Russian Mars Probe Already Had Fallen Before Dire Warnings

By Kathy Sawyer
Washington Post Staff Writer

THE WALL STREET JOURNAL

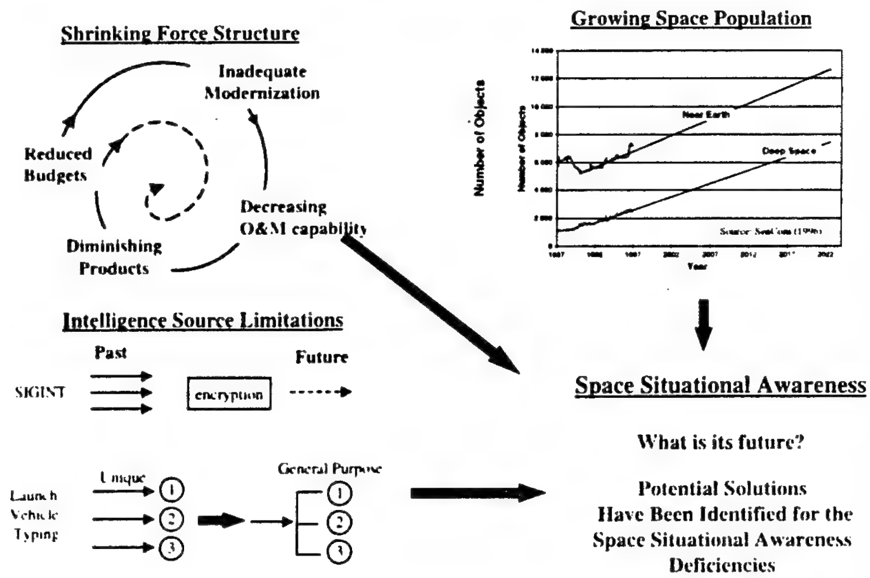
Sep 97

Russian space officials said a U.S. satellite came within 500 yards of the MIR Monday, and the space station's crew, fearing collision, waited out its passage in an escape capsule. NASA said the Russians were exaggerating the seriousness of the incident.

Other Issues

- Search vs track
  - How to find objects we have not seen before or that have been lost
    - Undetected, intentional satellite maneuvers
  - Impact of launch site proliferation and lack of optimally located sites for early space object tracking
- Accuracy
  - Necessary for Space Control (negation) operations
  - Conjunction prediction and subsequent need to maneuver

We are Losing the Ability to Provide Space Situational Awareness



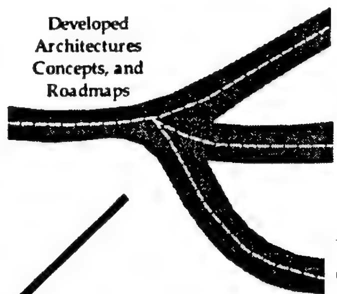
Recent Studies of Space Surveillance

- CINC'S Vision
- Space Control Architecture
- GAO Report
- ONMS
- JCS Study

Study Example
Optical Network Mission Study (ONMS)

ONMS Partners
Operators
Developers
Researchers

Developed Architectures Concepts, and Roadmaps



Space Based SSN

Mixed Ground and Space Based SSN

Ground Based SSN

Evaluated Architectures for technology and cost

- Analyses quantified decreasing capability
- Defined programs to resolve deficiencies
- Identified key ops demos and technology development to prepare for force structure decisions

SSA Measures and Solutions

Location and Movement
(Metrics)

Info content - Accuracy
(how closely can object be located at some time in the future)

Timeliness
(how soon can object be tracked)

Quantity
(Search capacity; how many objects can be tracked in a given time period)

Missions/Capabilities/Status
(Intell for IPB/BDA)

Info Content

Ops	Technical
Current Operations	Construction
Mission	Characterization
Status	Orientation
ID	Shape
	Stability

Timeliness

Quantity

Complementary Solutions

Complementary Info Content

Optical → Timeliness– (space-based optics)

High quantity GEO metrics & intel

Radar → Timeliness-- All-weather, day/night ops

High quantity LEO metrics & intel

Space Situational Awareness Process Flow

Discovery

NFLs
Maneuvers
Breakups
Lost objects
Deployments
Multiple P/Ls

Metrics

Track

ID

Catalog

Intell

ID

Characterize

Assess

Maintain SOB

AFSPC deficiencies

SC-2 Inadequate forces for complete space sit. awareness

Deep Space
Tracking
Capacity/ Coverage
GEO Status Change Detection

SC-3 Inadequate forces for SOB

GEO Intell

SOI/MPA Coverage
Near Earth Timeliness

SC-7 High cost of O&M of SSN/MWN

SC-9 Unable to maintain small object catalog

Source: 1997 AFSPC Space Control MAP (SSA deficiencies in top 10 SC list)

Deep Space Capacity/Coverage - Issues

Deep Space Population Growing

Catalog = 1577
Active and high drag = 737
Inactive with low drag = 840

Today's Coverage/capacity is inadequate

Military Implications

- Inability to monitor comm
  - C^2
  - Intel data

  } Frequent complaints by users
- Increasing potential for collision
- Uncertainty in adversary coverage
  - Comm for C^2
  - Missile detection
  - Intel collection

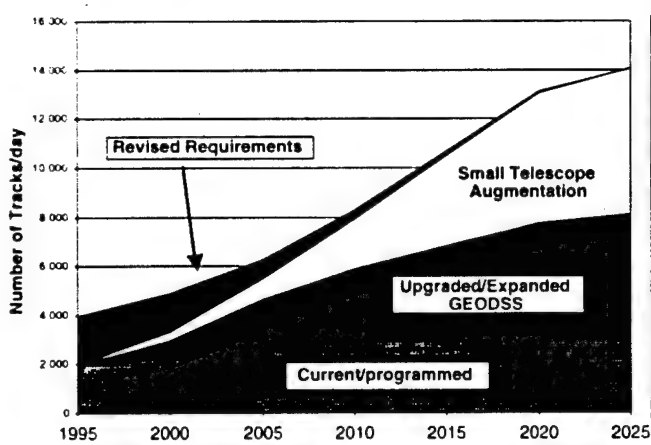
Courtesy: SenCom

Deep Space Capacity/Coverage - Solutions

Updated requirements
Distinguish tracking needs by object type and orbit class

Smart surveillance
Step-Stare vs tracking individual objects
Smarter tasking/tracking

Additional sensors
CCDs
Small telescopes
Exclusion zone sensors
Global coverage



Payoffs

Fewer "Lost" Objects

Current location info for intelligence exploitation

Less time "wasted" searching for lost objects

More complete catalog

Lower collision potential

SOI Capabilities in GEO Are Inadequate

Space Control Needs

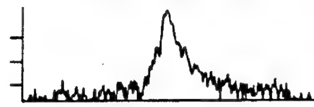
ID
Class and type

Status
Is it operational?

Characterization
Primary/secondary missions
Specific capabilities
Changes
Detailed characteristics

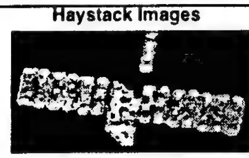
Current Capability in GEO

Haystack Range Profiles



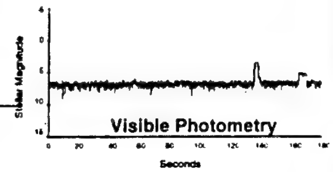
- Coverage limited to Haystack

Haystack Images



- Limited to few % of SOB
  - limited to Haystack coverage
  - No imaging capability for earth stable satellites

Deficiencies in GEO



- Limited ID & status determination
  — stable/unstable

Solutions for GEO SOI Needs

Space Control SOI Needs

- ID
  - Class and type
- Status
  - Is it operational?
- Anomaly resolution
- Characterization
  - Primary/secondary missions
  - Changes

Solutions

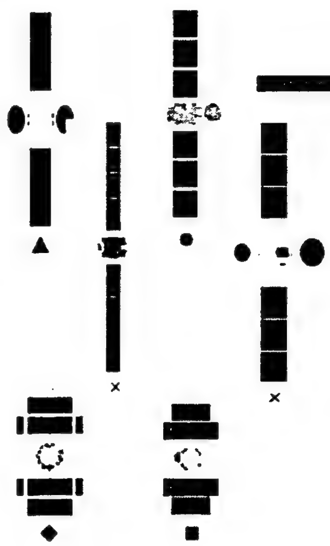
- Improve photometric data collection and exploitation
  - brightness
  - color
  - polarimetry
  - space-based
- Exploit NMD X-band radars to extend coverage
  - Range profiles
  - Imaging (rotating objects)
- Extend GEO imaging to earth-stable objects
  - Space-based fly-by

Payoffs

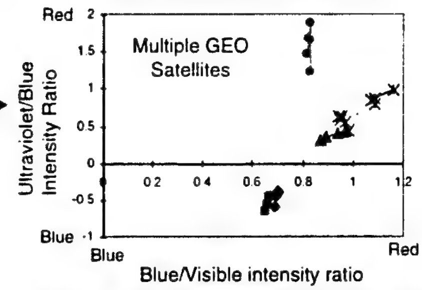
- More accurate status determination
- Potential for identification and orientation assessment
- Improved GEO coverage
- Improved anomaly resolution and damage assessment
- Detailed mission/capability characterization

GEO Intell Improvement Example: Exploit Color Photometry

Representative GEO Satellites



Color Photometry Facilitates ID



GEODSS has color filter locations

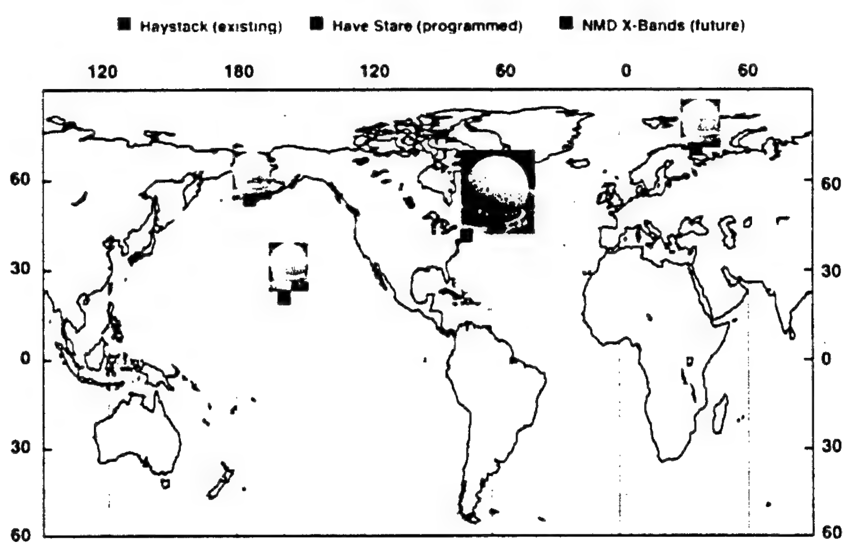
Payoffs

Contributes to Identification
- Permits exploitation

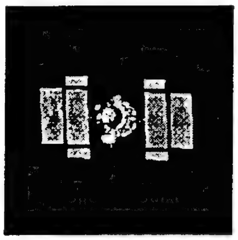
Potential for orientation detection
- Improved status determination
  - Better estimates of ops use

Help Reduce Mistagging

Exploit High-Power X-Band Radars to Improve GEO SOI Coverage (Range Profiling)



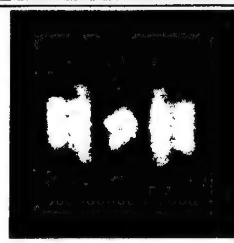
GEO Intell - Solutions
(Imaging)



Today

Future Imaging
- GB optical
- SB optical
- GB/SB radar(bistatic)

Imaging Concepts can provide adequate resolution for status and characterization



Payoffs

Accurate Status Determination
- Aware of military use
- Timely exploitation

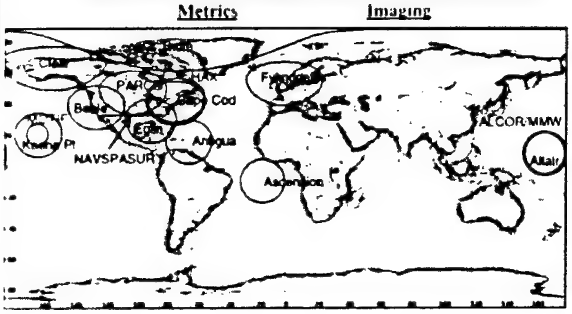
Mission/capability characterization
- Military utility known
  - Can take actions to avoid
- Secondary missions identified
  - Historically a weak area

Anomaly resolution/damage assess
- Support problem identification and resolution - eg MILSTAR
- Assess damage and potentially determine origin - natural etc

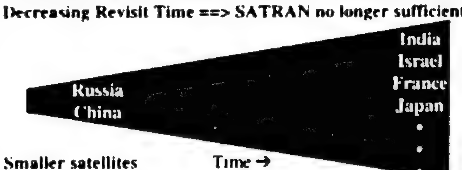
Near Earth Surveillance- Issues
(Maneuver Detection, Rapid Orbit Determination & Size Problems)

- Limited Observation Opportunities from Terrestrial Sites

Metrics Imaging



Increasing # of "Surveillance" satellites with maneuver capability
Decreasing Revisit Time ==> SATRAN no longer sufficient



Smaller satellites Time →
Growing number of launch facilities

Military Implications

Inability to know when/where adversary can observe our actions, troop location
- Lower mission success
- Higher casualties

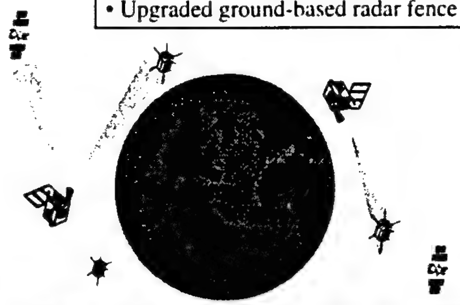
Inability to know when/where adversary does observe our actions, troop location

Increased probability of collision
- Critical at shuttle/ISS altitudes
- Historical examples

Near Earth Timeliness - Solutions

Metrics

- Space-based Electro-optic surveillance
- Upgraded ground-based radar fence



Near Term Ops Demos/Exps to Validate Concepts

- HEAT
- ASSET
- Wide Field of View Sensors
- Detailed analyses of ground based/space based alternatives

Payoff

- Current knowledge of all foreign recce spacecraft locations
  - Low risk of exposure of critical military operations
- Decreased probability of collision
- Better tip-off to new spacecraft and/or new capabilities
  - Limit earlier problems

SOI Capabilities in LEO Are Inadequate

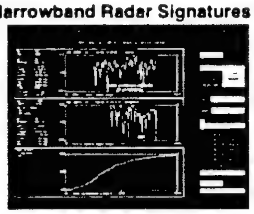
Space Control SOI Needs

- ID (class and type)
- Status
  - Is it operational?
  - What is it doing?
- Characterization
  - Primary/secondary missions
  - Changes
- Anomaly resolution

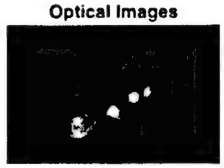
Current Capability in LEO

WB Radar Images

Narrowband Radar Signatures



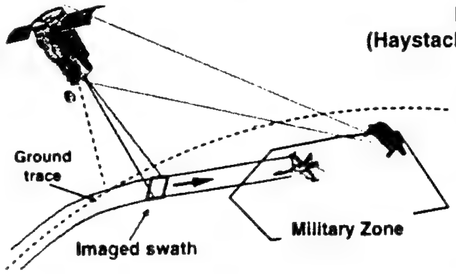
Optical Images

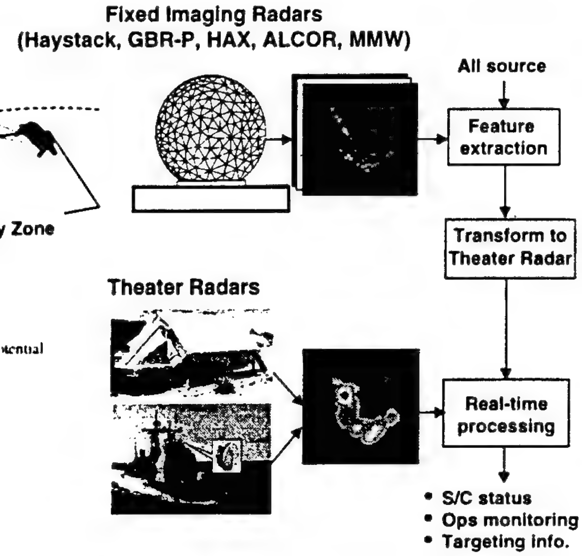


Deficiencies in LEO

- ID limited
  - Inadequate size and shape information for small satellites (< 1 m)
- Status determination limited by radar coverage
  - No theater coverage
- Characterization inadequate
  - Resolution inadequate for detailed characterization
- Anomaly resolution limited for small satellites

Near Earth Timeliness - Solutions
Theater Satellite Imaging Radar





Problem.

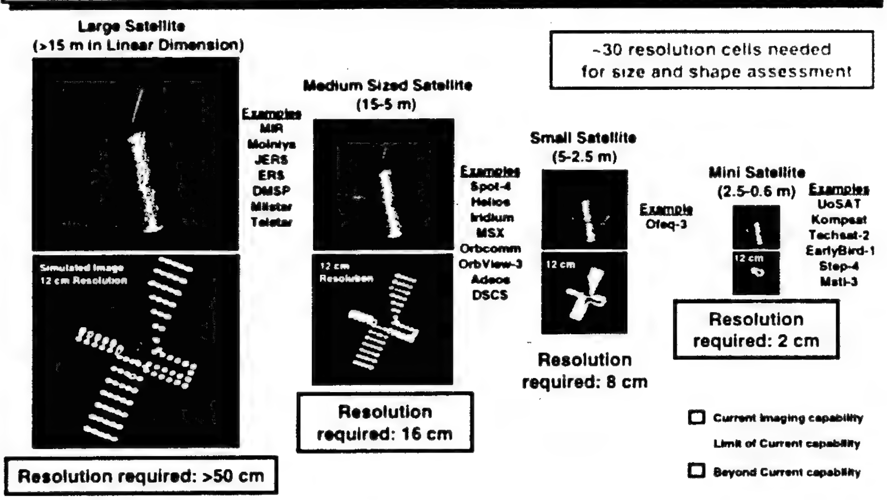
- Many new imaging satellites will be available to potential adversaries

Proposed Approach.

- Determine imaging satellite pointing using
  - Imaging radars in theater (e.g., THAAD-like Radar)
  - Stored high resolution satellite models and data

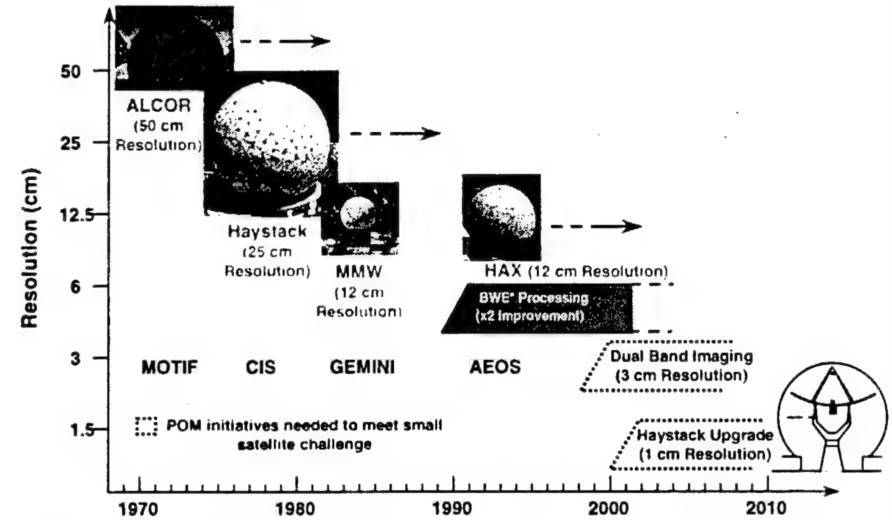
Satellite Mission & Payload Assessment (MPA)
Image Resolution Requirement

Problem: Current satellite image resolution is inadequate to assess small satellite MPA.
Challenge: To improve satellite image resolution by hardware and data processing enhancements



Satellites Imaging Solution

- Radar Resolution Improvements -



* BWE: Bandwidth Extrapolation

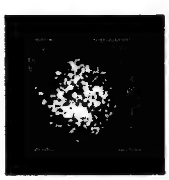
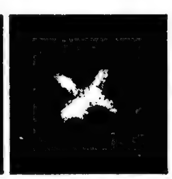
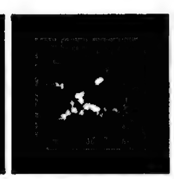
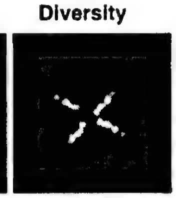
Near Earth Intell - Solutions

MSSS

Recent ADONIS Image

Hubble

GEMINI -Advanced Imaging Concepts - Computer Simulations
Target at 440 km, daylight

Raw	Bispectrum	MFBD	Phase Diversity	Super Res
				

Potential Solutions to AFSPC Deficiencies

SC-2 Inadequate forces for complete space sit. awareness
New Surveillance Techniques
Improved Algorithms
New Sensors
[illegible]

SC-3 Inadequate forces for SOB
Sensor Upgrades
New SOI Techniques
[illegible]

SC-7 High cost of O&M of SSN/MWN
Upgrade Sensors
New Operations
Selective Automation
[illegible]

SC-9 Unable to maintain small object catalog
New Sensors & New Algorithms
[illegible]

Summary

- SSA crital to warfighter
- Current/programmed force structure inadequate to do the job
- Potential solutions have been identified
- Send money

Space Situational Awareness

Essential

for

Military Operations

10 Jul 98

Background

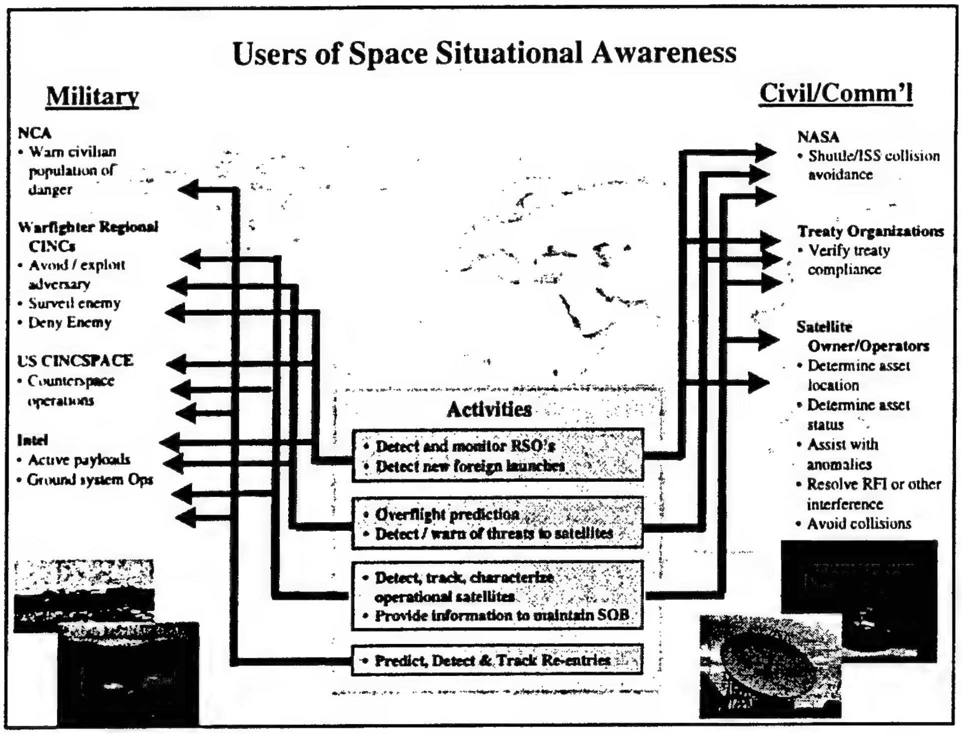
Military use of all classes of space systems is increasing
- **US/Allied**
- **Potential Adversary**

U.S. economic interests in space growing rapidly

Infrastructure for maintaining control of space is shrinking

Strong Leadership Support of Space Situational Awareness by:
- **National Space Policy**
  - "Modernize Space Surveillance..to detect...characterize threat to US space systems...and protection of military activities
- **USCINCSPACE**
  - "Space surveillance is the 'first order of business' at USSPACECOM"

Space Situational Awareness Modernization Needed



Warfighters Must Have Situational Awareness
Source Comparison

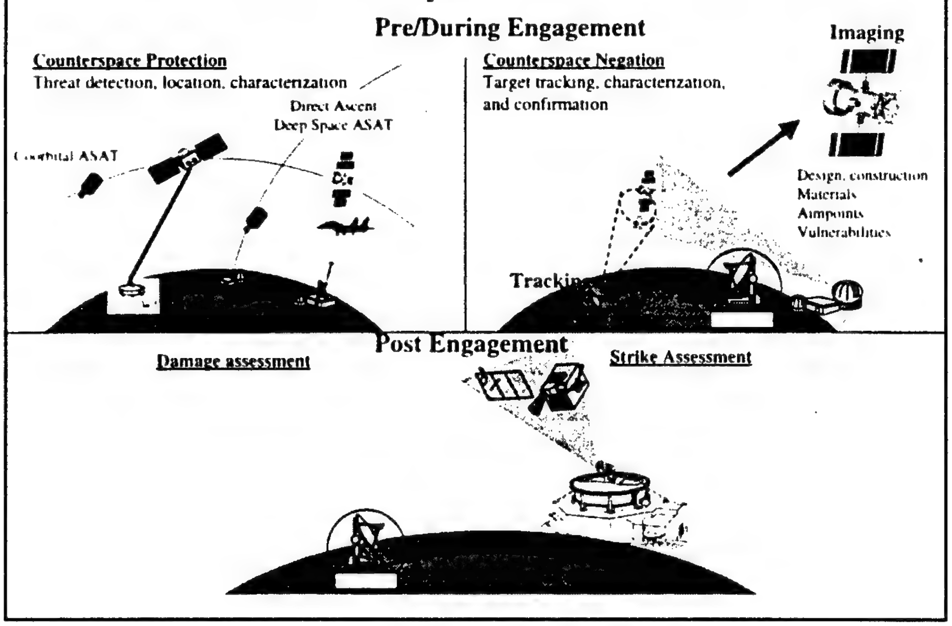
SA Information	Terrestrial Forces Sources for SA	Space Forces Sources for SA
Threat/target locations, motion, IFF Traffic control Order of battle	AWACS	SSN
Mobile threats/targets Fixed targets	JSTARS	SSN
Threat/target locations and operations from RF intercept	Rivet Joint National Systems	National Systems
Target/threat locations and characteristics	National systems	SSN National systems
BM/C⁴I	AOC/JIC	CMOC/CIC

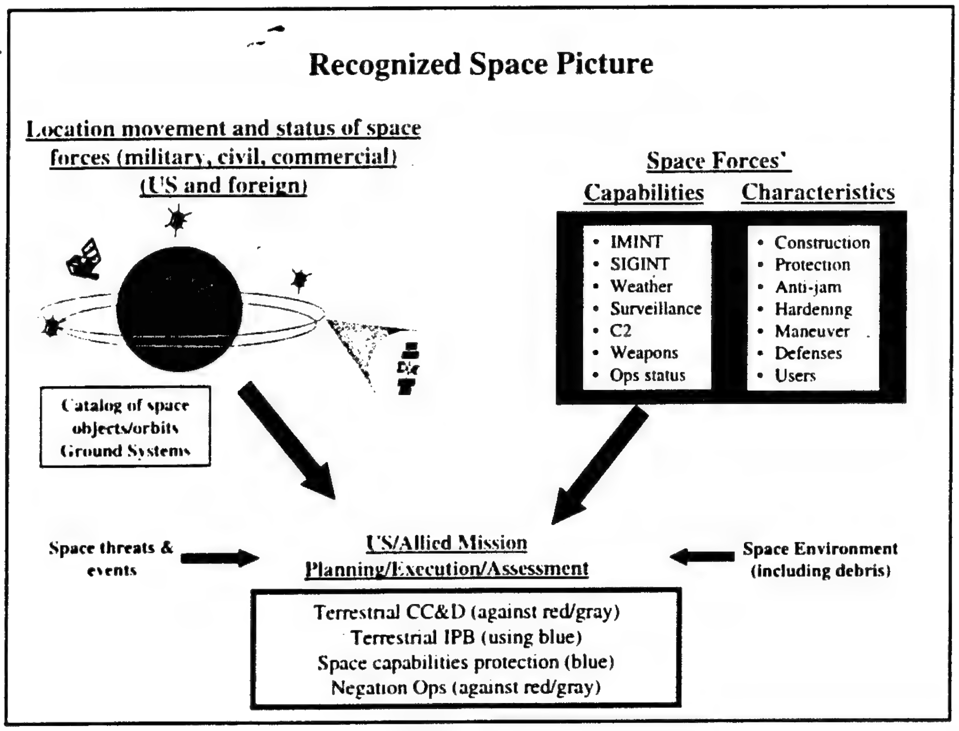
Warfighters wouldn't go to war without AWACS ...

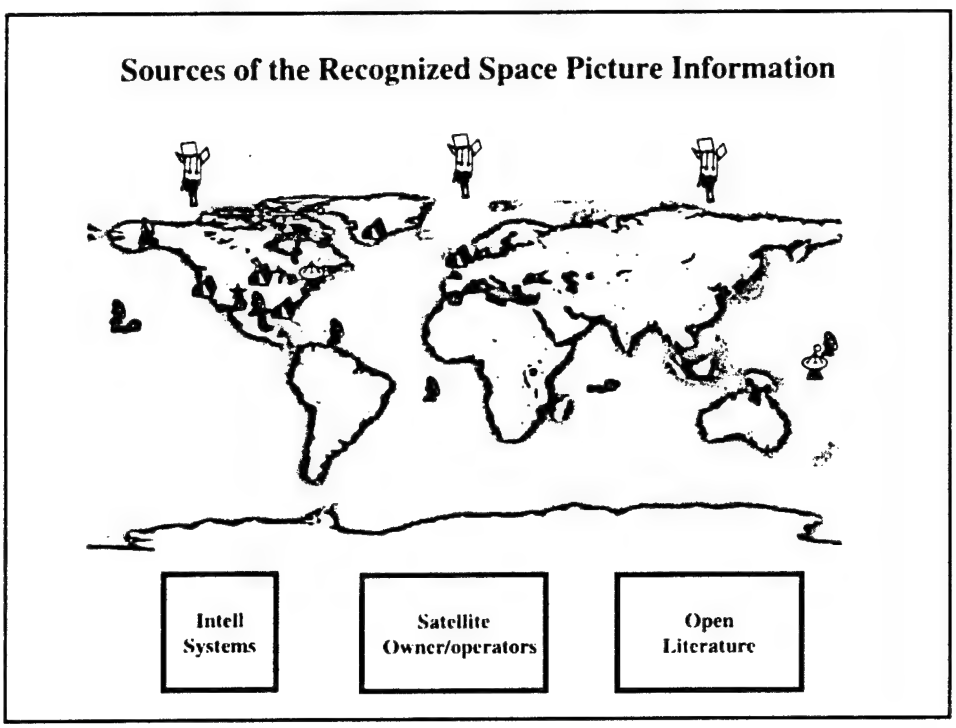
Space Situational Awareness Essential to Terrestrial Military Operations

OVERFLIGHT WARNING	THREAT WARNING
•Potential threats to our terrestrial forces and operations •Timing of overflight •Capabilities of ISR systems	•Potential threats to our space assets that support terrestrial SA and Intell Prep of the Battlefield •Timing of threat •Threat characteristics •Origin of threat
EXPLOITATION	**ANOMALY RESOLUTION & DAMAGE ASSESSMENT**
•Space C^2 capabilities and activities used by our adversaries •Assist intell collection	•Blue space systems used by US Military •Assist routine anomaly resolution •Assist damage assessment from natural and adversary causes

Space Situational Awareness Essential to Counterspace Operations



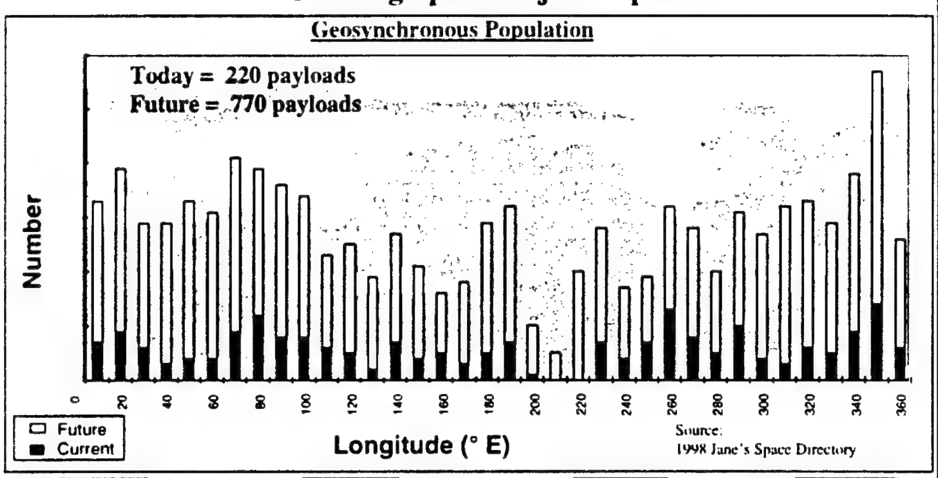

Recognized Space Picture
Location movement and status of space forces (military, civil, commercial) (US and foreign)
Catalog of space objects/orbits Ground Systems
Space Forces'
Capabilities
• IMINT
• SIGINT
• Weather
• Surveillance
• C2
• Weapons
• Ops status
Characteristics
• Construction
• Protection
• Anti-jam
• Hardening
• Maneuver
• Defenses
• Users
Space threats & events
US/Allied Mission Planning/Execution/Assessment
Space Environment (including debris)
Terrestrial CC&D (against red/gray)
Terrestrial IPB (using blue)
Space capabilities protection (blue)
Negation Ops (against red/gray)


Sources of the Recognized Space Picture Information
Intell Systems
Satellite Owner/operators
Open Literature

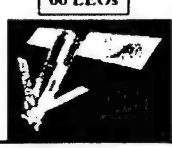
Challenges to Maintaining the Recognized Space Picture

- Growth in numbers of space objects
- Increased complexity of space payloads - multiple payloads/spacecraft
- Military use of commercial space capabilities--Owned/leased
- Small objects and manned presence in space
- Human presence in space
- Shrinking force structure
- Reduced ability to determine the characteristics, capabilities and ops status
- Launch platform diversity - numbers/locations, ground/sea/air launch

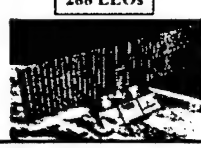
Growing Space Object Population



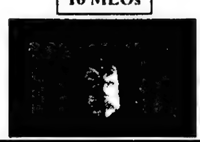
Iridium
66 LEOs



Teledesic
288 LEOs



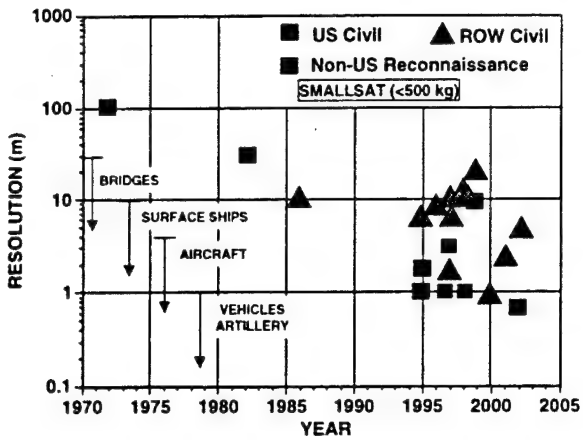
ICO
10 MEOs



Globalstar
56 LEOs

Growing Complexity of Active Payload Operations

- Growth in number and capability of foreign and commercial ISR systems
  - Optical, radar, sigint, elint
- Ability to image far from the nadir ground direction
  - "Where is it looking now?"
- Multiple, independently directed, narrow comm beams
- Orbit adjustments and maneuver



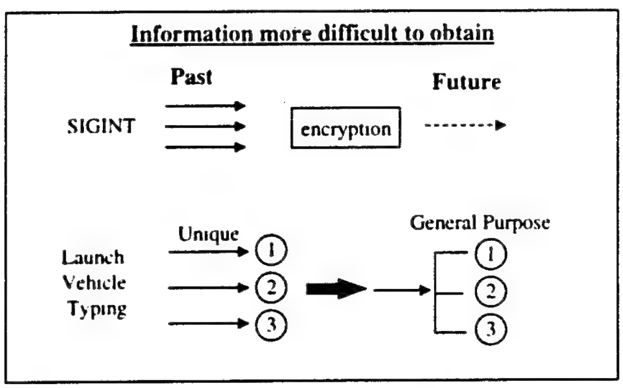
Space Intelligence Needs & Source Limitations

Space Control Needs

ID
Class and type

Status
Is it operational?

Characterization
Primary/Secondary missions
Changes
Detailed characteristics



- **Anomalous behavior appears to be more frequent**
  - **ADEOS**
  - **Earthwatch**
  - **Classified examples**
- **MASINT and imaging techniques have not kept pace**

U.S. Economic Interests in Space Need Space Situational Awareness

CINC Vision
"Global Partnerships"

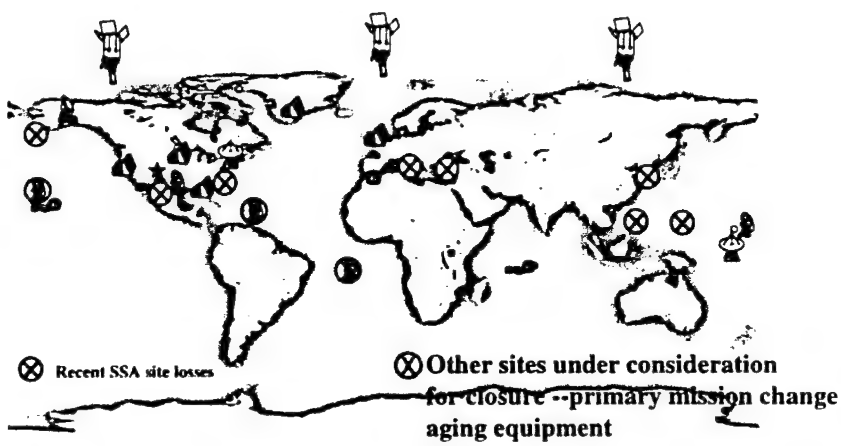
U.S. Military Leverages Huge Commercial Investment

Integrated Space "Traffic Control" and "Accident Investigation" to protect "Space Lanes for Commerce"

- Identification of safe launch corridors
- Detection and location of potential conjunctions of space objects
- Support to anomaly resolution and post mortem assessments

"$38 billion business today, $171 billion in less than a decade"
(International Space Industry Report, May 7 1998)

Site Closures



Intell Systems	Satellite Owner/operators	Open Literature

Aging Equipment

- GEODSS Vidicon Photomultiplier Tubes - 1970's technology
  - 1970s technology
  - Virtually impossible to obtain replacements
- Eglin
  - Aging tubes
  - Dedicated manufacturing lines
  - 1970s computers
- HAX-MIT/LL
  - Specialized tubes
  - One vendor

Many Recent Failures in Space Situational Awareness

SPACE NEWS July 96

Space Debris Damages French Defense Satellite

By LEONARD DAVID
Space News Correspondent

The Boston Globe

MISSILE DESTRUCTION RAISES FEARS OF SPACE DEBRIS

SOURCE: By David L. Chandler, Globe Staff

A Minuteman missile on a test flight over the Pacific Ocean last month was probably destroyed in a collision with a piece of space junk, aerospace analysts and spokesmen said yesterday.

Multiple Classified Examples

SPACE NEWS Aug 97

European, Russian Satellites Have Close Call in Orbit

By PETER B. de SELDING
Space News Staff Writer

The Washington Post Nov 96

Craft? What Craft? Russian Mars Probe Already Had Fallen Before Dire Warnings

By Kathy Sawyer
Washington Post Staff Writer

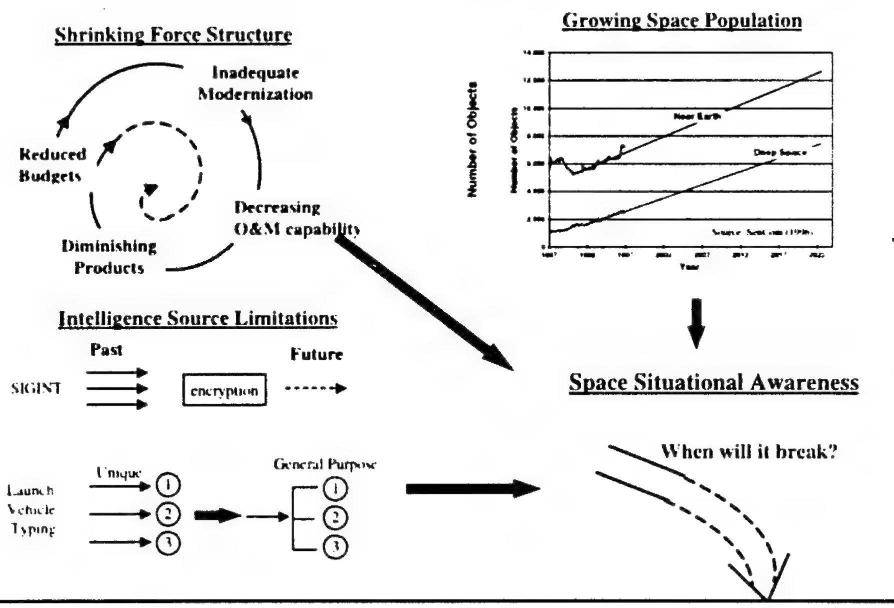
THE WALL STREET JOURNAL Sep 97

Russian space officials said a U.S. satellite came within 500 yards of the MIR Monday, and the space station's crew, fearing collision, waited out its passage in an escape capsule. NASA said the Russians were exaggerating the seriousness of the incident.

Other Questions

- How to discover objects not seen before, objects that have been lost, and unexpected events in space
  - Undetected, intentional satellite maneuvers, deployment
  - Break-ups, re-entries
- Impact of launch site proliferation and lack of optimally located sites for early space object tracking
- How to minimize maneuvers needed to avoid potential conjunctions
- What are the SSA needs for future counterspace operations - protection & negation
- How to improve ephemeris prediction efficiency

We are Losing the Ability to Provide Space Situational Awareness

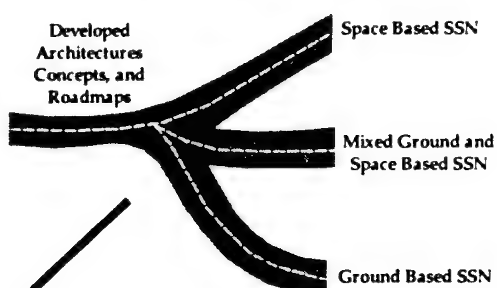


Recent Studies of Space Surveillance

- CINC'S Vision
- Space Control Architecture
- GAO Report
- ONMS
- OJCS Study

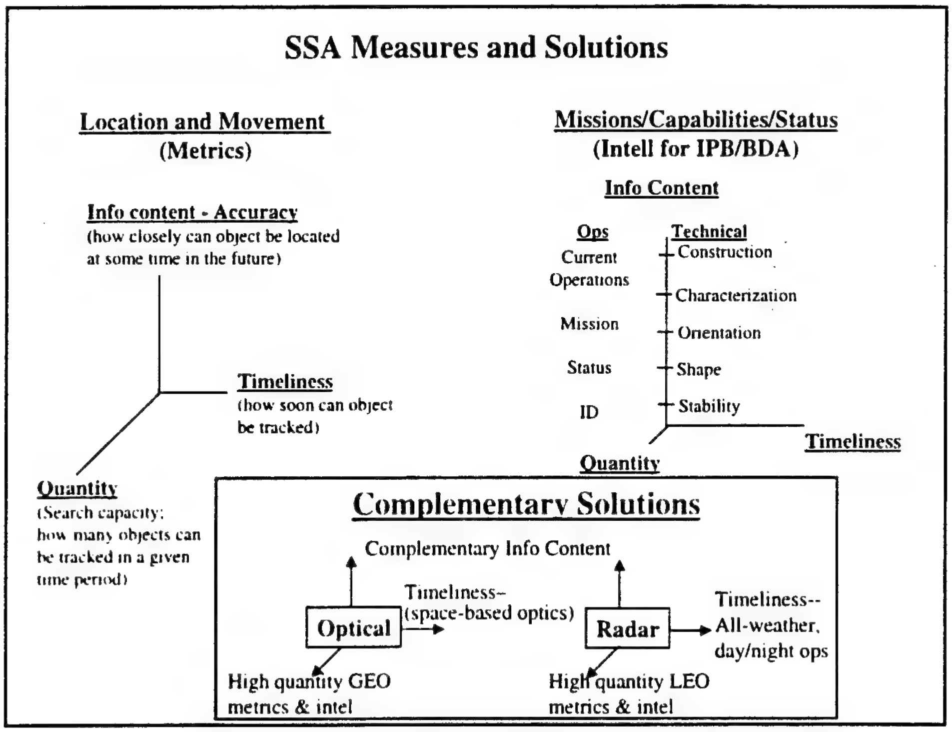
Study Example
Optical Network Mission Study (ONMS)

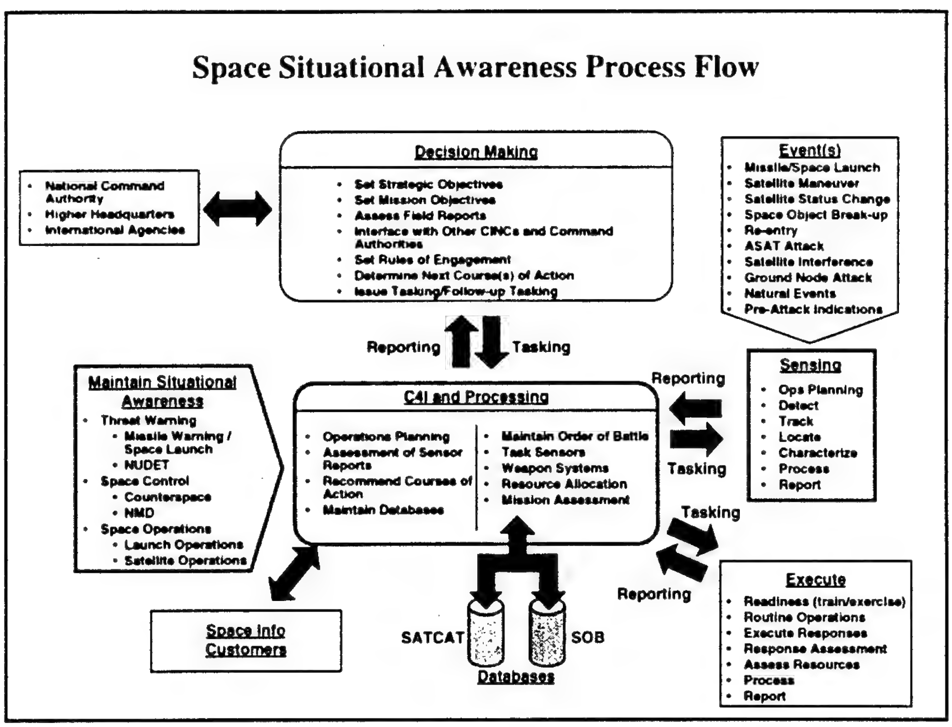
ONMS Partners
Operators
Developers
Researchers



Evaluated Architectures for technology and cost

- Analyses quantified decreasing capability
- Defined programs to resolve deficiencies
- Identified key ops demos and technology development to prepare for force structure decisions


SSA Measures and Solutions
Location and Movement
(Metrics)
Info content - Accuracy
(how closely can object be located at some time in the future)
Timeliness
(how soon can object be tracked)
Quantity
(Search capacity: how many objects can be tracked in a given time period)
Missions/Capabilities/Status
(Intell for IPB/BDA)
Info Content
Ops
Current Operations
Mission
Status
ID
Technical
Construction
Characterization
Orientation
Shape
Stability
Timeliness
Quantity
Complementary Solutions
Complementary Info Content
Optical
Timeliness–
(space-based optics)
High quantity GEO metrics & intel
Radar
Timeliness--
All-weather, day/night ops
High quantity LEO metrics & intel


Space Situational Awareness Process Flow
National Command Authority
Higher Headquarters
International Agencies
Decision Making
Set Strategic Objectives
Set Mission Objectives
Assess Field Reports
Interface with Other CINCs and Command Authorities
Set Rules of Engagement
Determine Next Course(s) of Action
Issue Tasking/Follow-up Tasking
Event(s)
Missile/Space Launch
Satellite Maneuver
Satellite Status Change
Space Object Break-up
Re-entry
ASAT Attack
Satellite Interference
Ground Node Attack
Natural Events
Pre-Attack Indications
Reporting
Tasking
Maintain Situational Awareness
Threat Warning
Missile Warning / Space Launch
NUDET
Space Control
Counterspace
NMD
Space Operations
Launch Operations
Satellite Operations
C4I and Processing
Operations Planning
Assessment of Sensor Reports
Recommend Courses of Action
Maintain Databases
Maintain Order of Battle
Task Sensors
Weapon Systems
Resource Allocation
Mission Assessment
Reporting
Tasking
Sensing
Ops Planning
Detect
Track
Locate
Characterize
Process
Report
Tasking
Reporting
Execute
Readiness (train/exercise)
Routine Operations
Execute Responses
Response Assessment
Assess Resources
Process
Report
Space Info Customers
SATCAT
SOB
Databases

AFSPC Deficiencies Related to SSA

SC-2 Inadequate forces for complete space sit. awareness

- Deep Space Tracking Capacity/ Coverage
- GEO Status Change Detection

SC-3 Update for Space Order of Battle

- GEO Intell
- SOI/MPA Coverage
- Near Earth Timeliness

SC-7 O&M for Threat Warning and Space Surveillance

SC-9 Maintain Small Object Catalog

SC-12 Operator Training for Space Control

SC-13 Process Orbit of Unique Space Assets

SC-14 Lack of Standardized Tools for Theater Space Ops

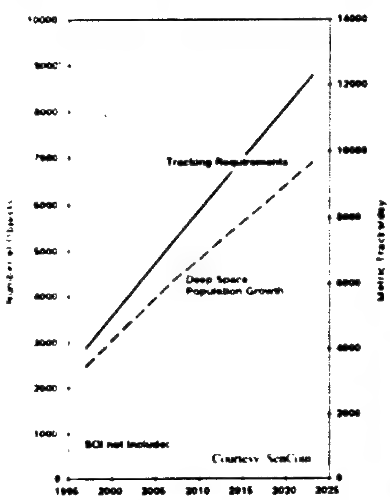
SC-15 No Collision Advisories

SC-16 No Detection of NEO's

Source: 1997 AFSPC Space Control MAP

Deep Space Capacity/Coverage - Issues

Deep Space Population Growing



> 50% of deep space catalog are inactive with low drag

<u>Today's Coverage/capacity is inadequate</u>

Current Requirements
- 1 or 2 tracks/day per object
- Independent of object orbit or type

Results
- "Requirements" tracks/day >> capability

Military Implications

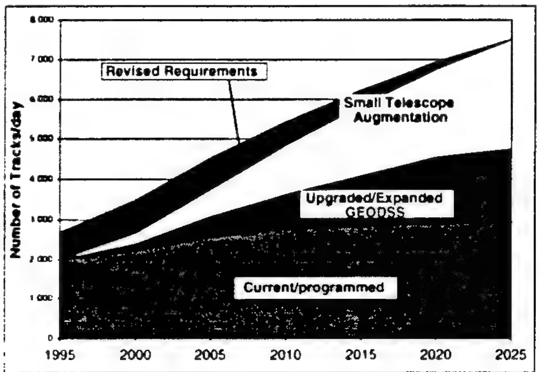
- Inability to monitor comm
  - C^2 } Frequent
  - Intel data } complaints by users
- Increasing potential for collision
- Uncertainty in adversary coverage
  - Comm for C^2
  - Missile detection
  - Intel collection

Deep Space Capacity/Coverage - Solutions

Updated <u>requirements</u>
Distinguish tracking needs by object type and orbit class

Smart <u>surveillance</u>
Step-Stare vs tracking individual objects
Smarter tasking/tracking

Additional <u>sensors</u>
CCDs
Small telescopes
Exclusion zone sensors
Global coverage



Notional -- Requires Additional Analysis

<u>Payoffs</u>

Fewer "Lost" Objects

Current location info for intelligence exploitation

Less time "wasted" searching for lost objects

More complete catalog

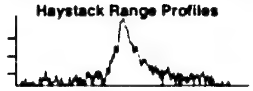
Lower collision potential

SOI Capabilities in GEO Are Inadequate

- Coverage limited to Haystack viewing

ID

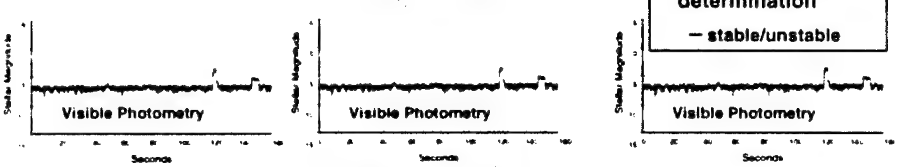
Inadequate



Inadequate

- Limited ID & status determination
  - stable/unstable

Status



Characterization

None

Haystack Images

- No imaging of earth stable satellites (>70% of SOB)

None

Solutions for GEO SOI Needs

Space Control SOI Needs

- ID
  - Class and type
- Status
  - Is it operational?
- Anomaly resolution
- Characterization
  - Primary/secondary missions
  - Changes
  - Specific capabilities
  - Detailed characteristics

Solutions

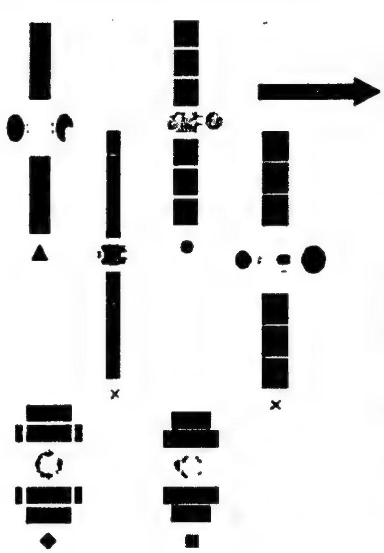
- Improve photometric data collection and exploitation
  - brightness
  - color
  - polarimetry
  - space-based
- Exploit NMD X-band radars to extend coverage
  - Range profiles
  - Imaging (rotating objects)
- Extend GEO imaging to earth-stable objects
  - Space-based fly-by

Payoffs

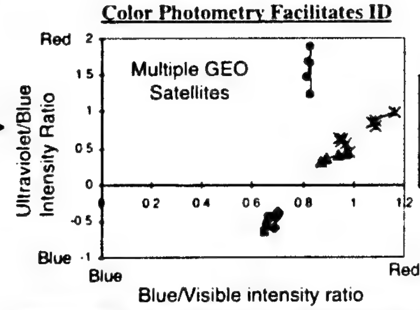
- More accurate status determination
- Potential for identification and orientation assessment
- Improved GEO coverage
- Improved anomaly resolution and damage assessment
- Detailed mission/capability characterization

GEO Improvement Example: Exploit Color Photometry for ID/Status Determination

Representative GEO Satellites



Color Photometry Facilitates ID



Can be done from GEODSS or space

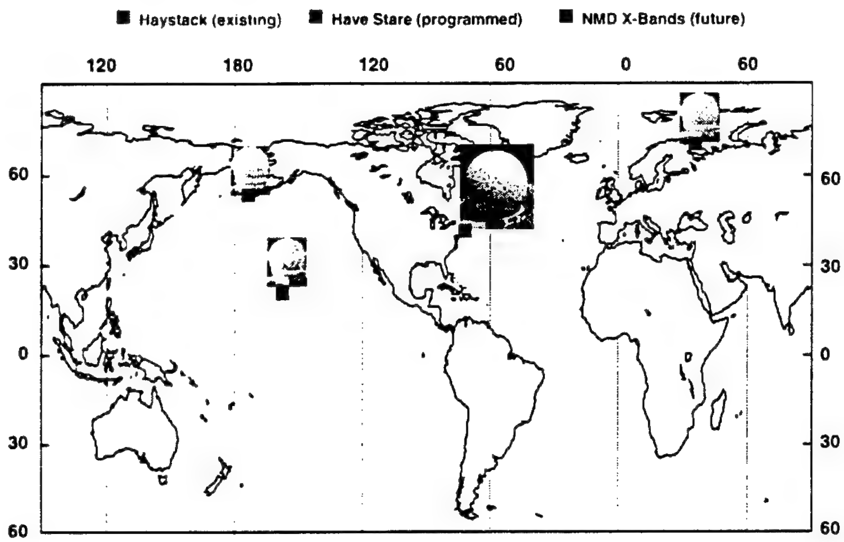
Payoffs

Contributes to Identification
- Permits exploitation

Potential for orientation detection
- Improved status determination
  - Better estimates of ops use

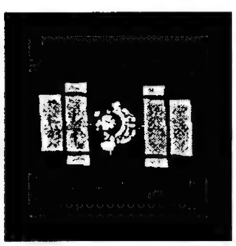
Help Reduce Mistagging

Exploit High-Power X-Band Radars to Improve GEO Coverage (Range Profiling for ID/Status Determination)



GEO Intell - Solutions

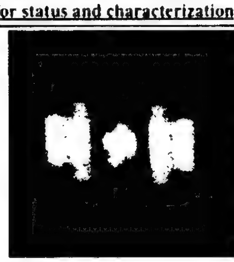
Imaging for ID, Status, Characterization and Anomaly Resolution



Today

Future Imaging
GB optical
SB optical
GB/SB radar(bistatic)

Imaging Concepts can provide adequate resolution for status and characterization



Payoffs

Accurate Status Determination
- Aware of military use
- Timely exploitation

Mission/capability characterization
- Military utility known
  - Can take actions to avoid
- Secondary missions identified
  - Historically a weak area

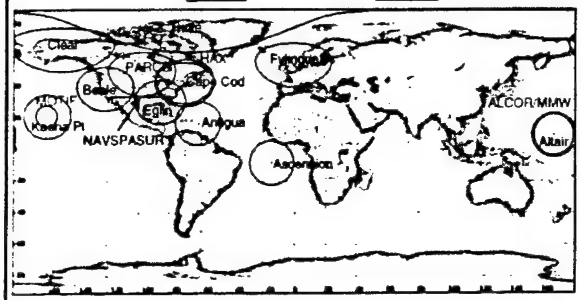
Anomaly resolution/damage assess
- Support problem identification and resolution - eg MILSTAR
- Assess damage and potentially determine origin - natural etc

Near Earth Surveillance- Issues

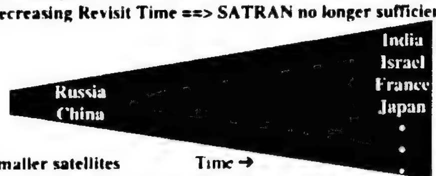
(Maneuver Detection, Rapid Orbit Determination & Characterization Problems)

Limited Observation Opportunities from Terrestrial Sites

Metrics **Imaging**



Increasing # of "Surveillance" satellites with maneuver capability
Decreasing Revisit Time ==> SATRAN no longer sufficient



Smaller satellites Time →
Growing number of launch facilities

Military Implications

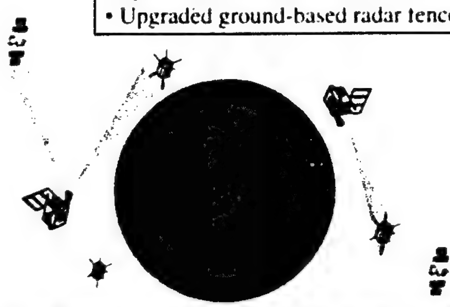
Inability to know when/where and how well adversary can observe our actions, troop location

- Lower mission success
- Higher casualties

Inability to know when/where and how well adversary does observe our actions, troop location

Near Earth Timeliness - Metric Solutions

- Space-based Electro-optic surveillance
- Upgraded ground-based radar fence



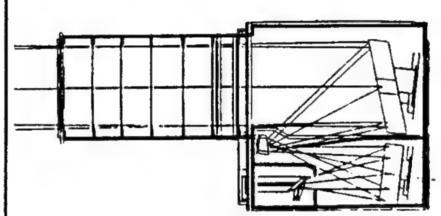
Near Term Ops Demos/Exps to Validate Concepts

- HEAT
- ASSET
- Wide Field of View Sensors
- Detailed analyses of ground based/space based alternatives

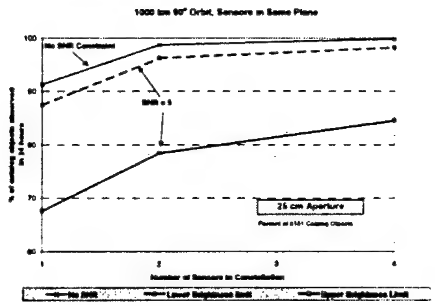
Payoff

- Current knowledge of all foreign recce spacecraft locations
  - Low risk of exposure of critical military operations
- Decreased probability of collision
- Better tip-off to new spacecraft and/or new capabilities
  - Limit earlier problems

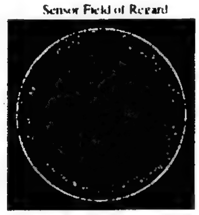
Space-based Visible Space Surveillance



SBV proves technology and conops



Streak Detection



- 4 ball constellation
- Dedicated or piggy-back or another host (e.g. SBIRS Low)
- Build on SBV conops

MPA Capabilities in LEO Are Inadequate

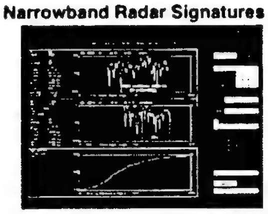
Space Control Needs

- ID (class and type)
- Status
  - Is it operational?
  - What is it doing?
- Characterization
  - Primary/secondary missions
  - Changes
- Anomaly resolution

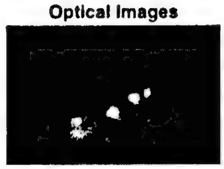
Current Capability in LEO

WB Radar Images

Narrowband Radar Signatures



Optical Images



Deficiencies in LEO

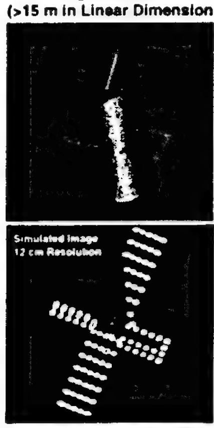
- ID limited
  - Inadequate size and shape information for small satellites (< 1 m)
- Status determination limited by radar coverage
  - No theater coverage
- Characterization inadequate
  - Resolution inadequate for detailed characterization
- Anomaly resolution limited for small satellites
- Timeliness insufficient

Image Resolution Requirements for Characterization

Problem: Current satellite image resolution is inadequate.
Challenge: To improve satellite image resolution by hardware and data processing enhancements

Resolution cells needed for size/shape assessment
Radar ~ 30
Optical ~ 10

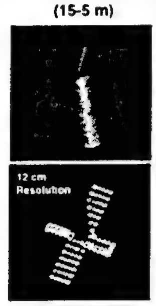
Large Satellite
(>15 m in Linear Dimension)



Examples
MIR
Molniya
JERS
ERS
DMSP
Milstar
Telstar

Resolution required:
Radar ~ 50 cm
Optical ~ 1.5 m

Medium Sized Satellite
(15-5 m)



Examples
Spot-4
Helios
Iridium
MSX
Orbcomm
OrbView-3
Adeos
DSCS

Resolution required:
Radar ~ 16 cm
Optical ~ 50 cm

Small Satellite
(5-2.5 m)

Example
Ofeq-3

Resolution required:
Radar ~ 8 cm
Optical ~ 25 cm

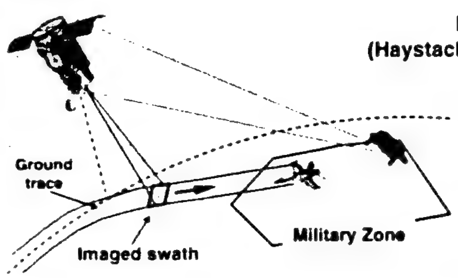
Mini Satellite
(2.5-0.6 m)

Examples
UoSAT
Kompsat
Techsat-2
EarlyBird-1
Step-4
Mati-3

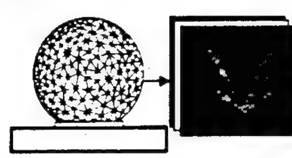
Resolution required:
Radar ~ 2 cm
Optical ~ 6 cm

Current imaging capability
Limit of Current capability
Beyond Current capability

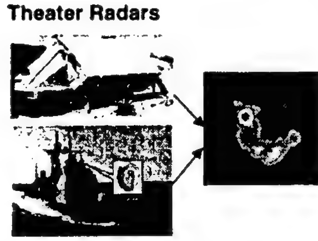
Near Earth Timeliness - Solutions
Theater Satellite Imaging Radar for ID/Status



Fixed Imaging Radars
(Haystack, GBR-P, HAX, ALCOR, MMW)



Theater Radars



All source → Feature extraction → Transform to Theater Radar → Real-time processing

- S/C status
- Ops monitoring
- Targeting info.

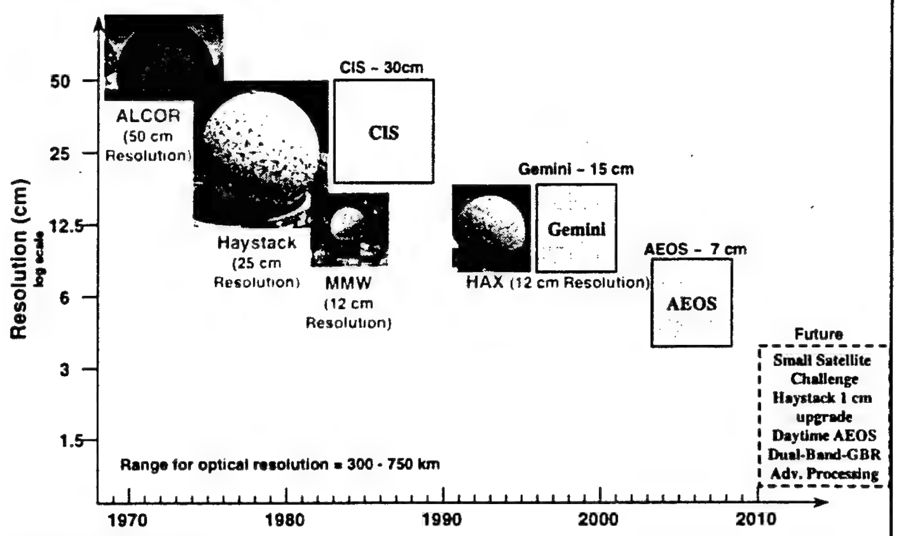
Problem

- Many new imaging satellites will be available to potential adversaries

Proposed Approach:

- Determine imaging satellite pointing using
  - Imaging radars in theater (e.g., THAAD-like Radar)
  - Stored high resolution satellite models and data

Satellites Imaging Solution

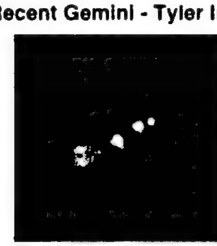


* BWE: Bandwidth Extrapolation

Near Earth Imaging - Optical Solutions

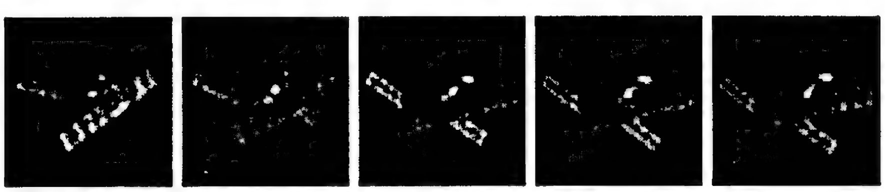
MSSS

Recent Gemini - Tyler Image



Hubble

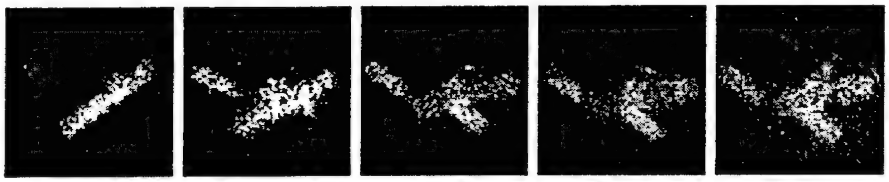
Starfire Optical Range Imagery



1.5 m telescope with adaptive optics, post processed by ERIM

Near Earth Imaging - Optical Solutions

SEASAT Images from Starfire Optical Range 1.5m telescope with Adaptive Optics



Advanced Multi-frame Image Reconstruction Algorithm
(ERIM International, Ann Arbor, MI)

Potential Solutions to AFSPC Deficiencies

SC-2 Inadequate forces for complete space sit. awareness
New Surveillance Techniques
Improved Algorithms
New Sensors

SC-3 Inadequate forces for SOB
Sensor Upgrades
New SOI Techniques

SC-7 High cost of O&M of SSN/MWN
Upgrade Sensors
New Operations
Selective Automation

SC-9 Unable to maintain small object catalog
New Sensors & New Algorithms

Summary

- **SSA critical to warfighter**
- **Current/programmed force structure inadequate to do the job**
- **Potential solutions have been identified**
- **Investment decisions required**

Deep Space Catalog Tracking Frequency

Today's approach to tracking: mean time between tracks

• Active payloads and objects with perigee height < 600 km	■ Mean	=	2.78	days	737 RSOs
	■ St. dev	=	2.4	days	
• Inactive objects with perigee height > 600 km	Mean	=	3.85	days	840 RSOs
	■ St. dev	=	3.0	days	

Recommended Approach

- For 215 Active, non-US - one track per day (78 Rus & PRC and 137 Row)
- For 108 active, US - maintain vigilance for protection (some of 137 Row may require protection)
- For 840 inactive, high perigee - reduce tracking frequency to > 30 days
  - High accuracy data & high accuracy orbits
  - Long-term propagated element set
- For 414 inactive, low perigee reduce tracking frequency to ~ 10 days

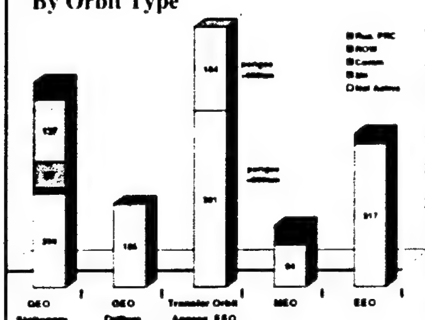
Less time tracking Inactive, high perigee ⇨ more time to support search and protection

Strategy for Additional Deep-Space Objects

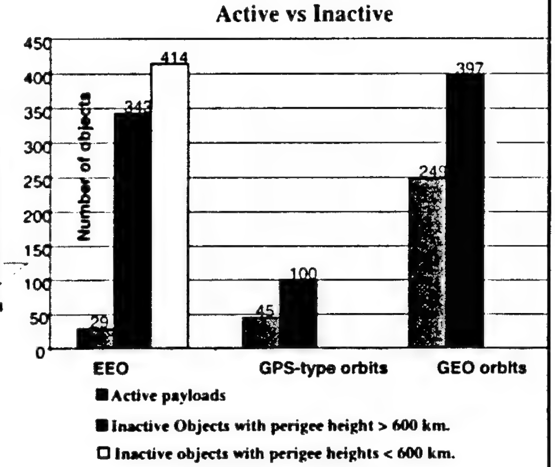
	Category	Action
170	Lost cataloged objects	Search (Electro-optical)
200	Exclusion list objects	
460	Lost analyst objects	Search (EO)
15	Low eccentricity analyst objects	Reduce tracking frequency to 30 days
285	High eccentricity analyst objects	Reduce tracking frequency to 10 days
1130	Total additional	

Today's HEO Object Population
(30 cm and Larger)

By Orbit Type



Active vs Inactive



Population expected to double in 18 years
Most growth expected in inactive objects

Catalog = 1577
Active and high drag = 737
Inactive with low drag = 840

Lost HEO Objects are a Near Term Processing / Organization Problem

Today's approach to tracking: mean time between tracks

• Active payloads and objects with perigee height < 600 km	Mean = 2.78 days	St. dev = 2.4 days	737 RSOs
• Inactive objects with perigee height > 600 km	Mean = 3.85 days	St. dev = 3.0 days	840 RSOs

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- For 840 inactive, high perigee - reduce tracking frequency to > 30 days
  - High accuracy data & high accuracy orbits
  - Long-term propagated element set
- For 414 inactive, low perigee - reduce tracking frequency to TBD

Less time tracking Inactive, high perigee → more time to support search and protection

HEO Capacity / Coverage

Catalog maintenance capacity: Inadequate sensor capacity with today's processing / organization but adequate for recommended approach

Implementation required

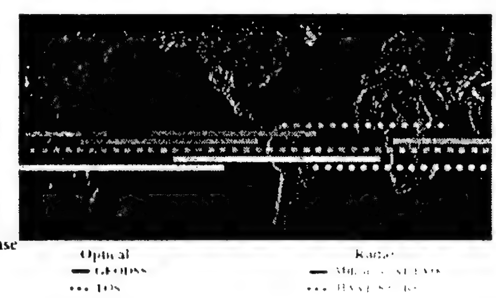
- Shift in thinking for Catalog Maintenance
- Processing outside of SPADOC
- Processing Implementation

Protection / prevention capacity

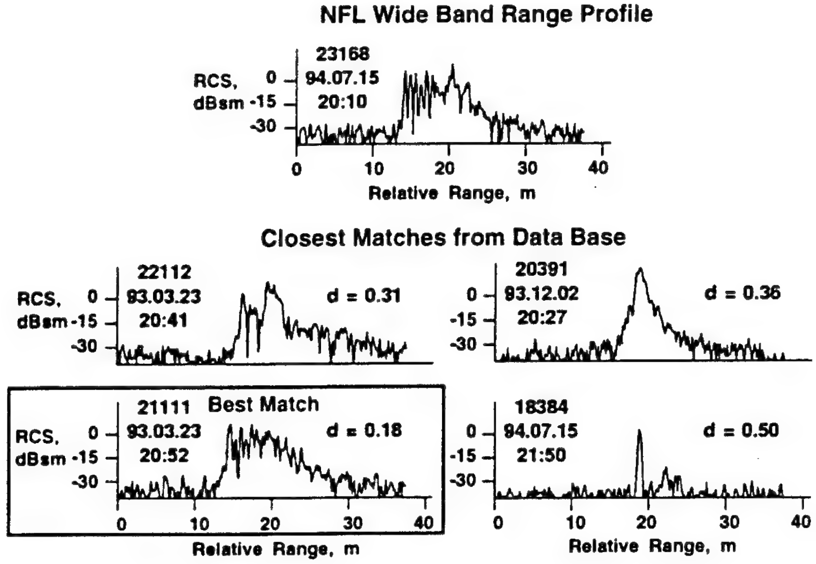
Improvements required

- Limited capacity of radars
- Weather limitations of ground-based optical
- Space-based optical or distributed ground-base optical may be needed

GEO Belt Coverage



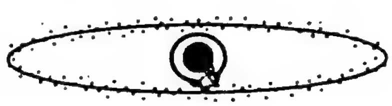
X-Band Radar Application Example: GEO New Foreign Launch (NFL) Identification



Deep Space Situational Awareness Architecture Changes for The Future

Complete GEO Coverage for Metrics

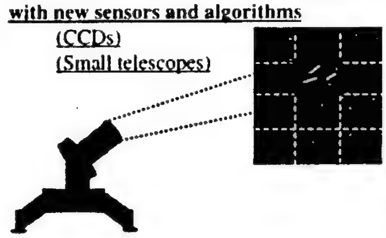
Space-Based Optical Sensor



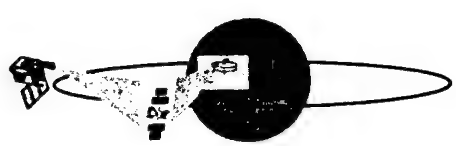
High Capacity Deep Space tracking with new sensors and algorithms

(CCDs)

(Small telescopes)

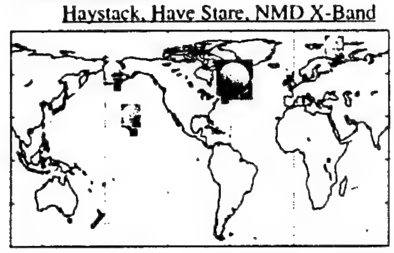


Space-based and Ground-Based Optical Imagery



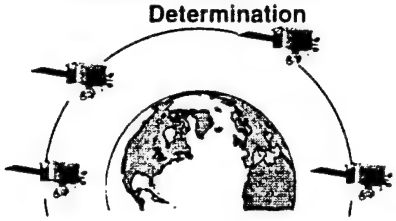
Timely GEO SOI with High Power X-band Radars

Haystack, Have Stare, NMD X-Band

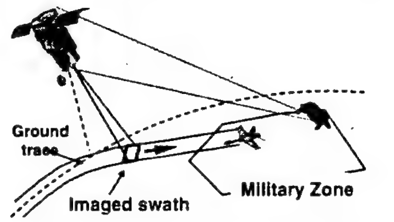


LEO Space Situational Awareness Architecture Changes for The Future

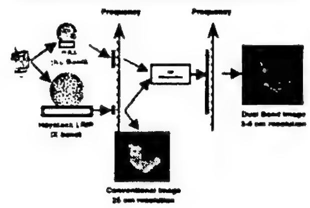
Space Based Sensors for Timely LEO Maneuver Detection and Orbit Determination



Theater Imaging for Real-time Detection of Hostile Operations



Radar Resolution Upgrades for Small Satellite Characterization



AEOS

Recommendation

Available from R. Benedict

Actions

Available from R. Benedict

Debris

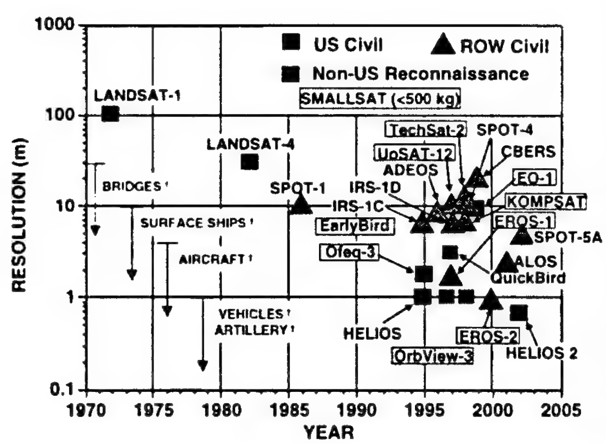
- NASA Requirements
  - Required : Catalog of > 5 cm.- sized RSOs with perigee altitudes < 600 Km
  - Goal : Catalog of > 1 cm.- sized RSOs with perigee altitudes < 600 Km.
- Principal Technical Challenges
  - Timely discovery : Large search area and detection sensitivity needed
  - Tracking : High accuracy sensors needed
  - Accurate Orbits for threat objects : Near-real-time atmospheric drag modeling needed
  - Cataloging : ~ 5000 RSOs for > 5 cm. - feasible at present
    ~ 50000 RSOs for > 1 cm. - new paradigm required

Debris Solutions : Low altitude

- **5 cm. network**
  - **FPS-85 and COBRA DANE for discovery**
  - **Precision sensors for follow-up**
    - **Radars**
      - **MHR, HAX, TRADEX, HAVE STARE,**
    - **Optical**
      - **Large telescopes**
      - **LADAR**
- **1 cm. network**
  - **Upgraded NAVSPASUR needed for discovery**
  - **Precision radars for follow-up**
    - **Radar**
      - **HAVE STARE, Haystack, GBR-O**
    - **Optical**
      - **Large telescopes**
      - **LADAR**
  - **New cataloging paradigm : include only RSOs that are in conjunction with space station**
  - **Near-real-time atmospheric drag modeling essential**
- **Experimental work required to refine/optimize options**

Growing Complexity of Active Payload Operations

- Growth in number and capability of foreign and commercial ISR systems
  - Optical, radar sigint, elint
- Ability to image far from the nadir ground direction
  - "Where is it looking now?"
- Multiple, independently directed, narrow comm beams
- Orbit adjustments and maneuver



Debris Solutions: High eccentricity orbits

- Debris population unknown
  - Density measurements needed to quantify threat
  - Haystack radar, ETS, upgraded GEODSS, Starfire and AEOS available for measurements
- Optical systems are preferred solution
  - 1 meter class for 5 cm. network
  - 3 meter class for 1 cm.
  - Multiple systems (~5) needed
  - Haystack and HAVE STARE can also provide follow-up

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WORKING DRAFT

HI-CLASS Utility Study Approach

2 Nov 98

Linda L. Crawford

Schafer

Study Objective

- To evaluate the operational use of a HI-CLASS system to support Space Situational Awareness tasks and requirements

3

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Study Approach

Task 1: Allocate Operational Tasks/Requirements

- Review the Space Surveillance/Space Control documents
  - 1995 AFSPC Space Surveillance Requirements Document
  - 1997 Space Control MAP
  - 1998 USSPACECOM Space Control Capstone Requirements Document - Space Surveillance Annex - draft
  - 1998 AFSPC/DOYO Requirements/Mission Area Assessment -draft
    - Meeting with AFSPC/DOYO and DRCS scheduled for 10 Nov
- Allocate applicable ones to HI-CLASS
  - High accuracy data generation and prediction, precision conjunction prediction support, debris tracking, sensor calibration, imagery data
- Document requirements summary in technical report

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Study Approach (cont)

Task 2: Host High Accuracy Data Workshop

- Host a high accuracy data workshop
  - Determine how the highest accuracy orbital data can be obtained
  - Determine how that data supports the operational tasks and requirements
  - Start with Requirements Summary (Task 1)
- Have 2 or 3 meetings (one day each separated by a month)
  - First (and second, if required) meeting: Discuss workshop objective, needs/visions of future applications, have participants brief techniques for obtaining high accuracy data
    - » E.g., advanced astrodynamic algorithms, precise data collection systems (HI-CLASS, other ladar systems), available software
  - Last meeting: Present results
    - » Summary of high accuracy needs
    - » Summary of high accuracy projects
      - Current, Future
    - » Recommendations
- Document workshop results in technical report

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Study Approach (cont)

Task 2: Host High Accuracy Data Workshop (cont)

- Suggested Participants
  - SWC/AE (Dr. Liu, Dr. Kaya, Dr. Snow, Mr. Morris, Mr. Daw)
  - USSPACECOM/AN (Col Alfano, LtCol Vallado - Dec 98)
  - NAVSPACECOM/N6 (Dr. Schumacher)
  - Naval Research Laboratory (Dr. Coffey, Dr. Gilbreath)
  - AFRL
    - » VS (Capt Sabol, Dr. Burns)
    - » DEBS (Dr. Matson)
  - Draper Laboratory (Dr. Cefola)
  - MIT/LL (Dr. Gaposchkin, Dr. Czerwinski)
  - Support Contractors
    - » Schafer - Ms. Crawford
    - » SAIC/CoSpgs - Mr. Larson
    - » ITT/CoSpgs - Mr. Barker, Mr. Wallner
    - » GRC/CoSpgs - Dr. Hoots, Mr. Neal
    - » CSA/CoSpgs - Mr. Roehrich

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Study Approach (cont)

Task 3: Interface with Developer Contractor

- Provide technical support to program development
  - Ensure no duplication of effort
  - Establish synergy between activities
- Attend major technical meetings for information exchange

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Study Approach (cont)

Task 4: Develop Concept of Operations

- Determine role of the HI-CLASS system
  - Based on requirements summary, workshop findings, and current project specification/task order
  - Include capabilities (e.g., data collection, data processing), logistics, documentation, etc.
- Develop a high level CONOPS on HI-CLASS' utility in meeting the operational tasks/requirements
- Document CONOPS in technical report

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Study Approach (cont)

Task 5: Develop Roadmap

- Document activities to ensure the system being developed shows operational utility
- Suggest experiments (and approaches) to demonstrate potential of HI-CLASS
  - Accurate metric data collection and generation
  - Imagery
    - » Range resolved and Doppler
    - » Day/night
    - » Low elevation angle
  - Responsiveness to tasking
    - » Metric and Imagery
  - Debris tracking
  - Sensor calibration
- Document roadmap and experiment activities in technical report

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Study Approach (cont)

Task 6: Develop HI-CLASS Briefing

- Develop and present HI-CLASS Briefing
  - Results of study
  - Advocate system
    - » Operational demonstrations/experiment results
    - » Utility

Schafer

Summary of Task Deliverables

- HI-CLASS Requirements Summary Technical Report
- High Accuracy Requirements Workshop Technical Report
- HI-CLASS CONOPS
- HI-CLASS Roadmap
- HI-CLASS Briefing

Schafer — Estimated Schedule, LOE, Travel

- Study Duration - six months (1 Nov 98 - 1 May 99)
- Tasks Schedule/Level of Effort
  - Task 1: Allocate Requirements/Tasks - between 1 - 30 Nov 98, 40 hrs
  - Task 2: Host High Accuracy Workshop - between 1 Jan - 15 Apr 99, 120 hrs
  - Task 3: Interface with developer contractors - between 1 Jan - 1 May 99, 40 hrs
  - Task 4: Develop CONOPS - between 1 Dec 98 - 1 Feb 99, 40 hrs
  - Task 5: Develop Roadmap - between 1 - 28 Feb 99, 40 hrs
  - Task 6: Develop Briefing - between 1 - 31 Mar 99, 40 hrs
- Travel
  - 2 trips, 2 days to Colorado Springs
  - 1 trip, 4 days to Maui

Schafer — Summary

- Study approach has been developed
  - Resources have been identified and most are readily available
  - Schedule and LOE are estimates
    - Long lead time is the High Accuracy Workshop
- Schafer is ready to start with AFRL/DEBS concurrence

HI-CLASS Laser Radar Operational Utility Analysis

and

Roadmap

prepared for

Air Force Research Laboratory (AFRL)/DEBS

4 January 1999

Schafer

2000 Randolph Road, Suite 200
Albuquerque, NM 87106

4

TOC
[to be inserted]

1.0 INTRODUCTION

This report will document the following:

a) the operational roles and concept of operations of how the HI-CLASS system can support user requirements and tasks in the areas of Space Surveillance and Space Control.

b) the activities that must be completed to determine the operational utility of the HI-CLASS system, and

c) the required milestones in the development of the HI-CLASS system to transition to an operational surveillance asset.

2.0 BACKGROUND

2.1 System Description

The HI-CLASS (High Performance Co2 Ladar Surveillance Sensor) is a wide bandwidth, wavelength agile ladar radar under development in phases to determine the operational utility of such technology to support user requirements. The system has several modes of operations:

a) ladar that addresses acquisition and tracking, illumination, return signal detection and processing to establish target range, range rate, angular position, and imaging data of satellites.

b) lidar that pertains to detection and classification of vapor species via characteristic spectral absorption of ground backscater of transmitted CO2 radiation.

2.2 Air Force Space Command's Space Surveillance Mission

The Space Control Mission has a task to provide Space Situational Awareness (SSA) via Space Surveillance Operations. Space Surveillance Operations has the following tasks:

a) Provide Battle Management/Command and Control (BM/C^2) for space surveillance forces

b) Monitor Space through the collection, processing, and assessing of data, as well as maintain the databases. This task has several sub-tasks as follows:
   1) Detect and tract Resident Space Objects (RSOs)
   2) Collect data for the Space Order of Battle (SOB)
   3) Detect and track Near Earth Objects (NEOs)

c) Analyze data and inform space users, to include Theater Operations, Space Operations, Intelligence Needs, and Treaty Monitoring.

d) Support Counterspace to include Protection and Negation.

Support includes

a) providing updated orbital parameters and overflight notification of space-based reconnaissance satellites

b) supports missile warning by assisting in the correlation of Reentry Vehicle detections (by associating them with reentering space objects or errant launches) and the location, tracking, and impact prediction of errant ballistic (sub-orbital) trajectories.

c) provides common-reference locations and course of US and foreign space assets to military forces for use in the friendly exploitation of those assets.

d) forwards data to numerous agencies involved in intelligence collection operations or who are conducting Scientific and Technical (S&T), Mission and Payload Assessment (MPA), Strategic and theater Indications and Warning (I&W), and operational intelligence evaluations.

e) Support to Orbital Safety (collisions with other orbiting objects and accidental laser illumination), Early Orbit Determination (EODET), space system or geophysical anomalies assessments.

f) timely and accurate detection, tracking, identification, processing, reporting, and analysis of activities, and changes in operational status and orbits for SOB payloads .

Space Surveillance Operations are accomplished through a network of world-wide sensors, command and control (C^2) facilities, intelligence centers, and associated computers, processing and communications support. The Space Surveillance Network (SSN) includes many of the surveillance assets that support Space Surveillance, but the mission is augmented by other centers such as the North American Aerospace Defense Command (NORAD)/United States Space Command (USSPACECOM) Combined Intelligence Center (CIC).

Space Surveillance Requirements
Working Paper
Linda L. Crawford

Background

Between 1958 and 1993 there were approximately 70 space surveillance-related documents. In 1993 AFSPC started activities to review the current Space Surveillance Network (SSN) and its requirements, and to develop a Space Surveillance Mission Area Plan (MAP), as part of the AF Modernization Process. The MAP process included identifying the mission needs, developing operational requirements and operational concepts/tasks, evaluating the ability to accomplish the tasks using current and future systems.

AFSPC compiled from the prior requirements documents and user inputs the AFSPC Space Surveillance Requirements Document (SSRD), dated 10 Jul 95. This document is a "system of system" level requirements document and lists Space Surveillance Network (SSN) requirements in terms of type of data (metrics, intel), quantity, quality, and timeliness. The document was provided by AFSPC to USSPACECOM to support the development of a USSPACECOM Space Control (that includes Surveillance) Capstone Requirements Document (CRD).

USSPACECOM developed a Space Control Mission Need Statement (MNS), which includes Space Surveillance, Counterspace, and National Missile Defense. USSPACECOM then followed up by developing the Space Control CRD, which referenced the AFSPC SSRD. This CRD, dated 20 Mar 98, is in the validation process. The CRD stated that a Space Surveillance Annex, using an updated version of the SSRD, would be developed (status unknown).

In summary, the primary Space Surveillance requirements documents are (this set of documents is still valid for any follow-on requirements analysis):

1) AFSPC Space Surveillance Requirements Document (SSRD), 10 Jul 95
   - has quantitative timeliness, accuracy, quantity, and type of data requirements
   - augment with NASA's orbital debris requirements

2) USSPACECOM Space Control Mission Need Statement (MNS), 1997
   - no qualitative requirements - five pages maximum

3) USSPACECOM Space Control CRD, draft, 20 Mar 1998

4) USSPACECOM Space Surveillance Annex to Space Control CRD

5) AFSPC 1997 Space Control MAP, Sep 97

Another set of requirements (most included in the 1995 SSRD, but not in as much detail) are listed in the Updated Requirements for SSN SOI Sensors letter from USSPACECOM/J2FS - also has attached the SOI Statement of Need (1989).

The USSPACECOM Instruction 10-40, Space Surveillance Operations, is considered a "lower level operational requirements" document. There are some timeliness requirements (e.g., get SOI out within certain time period), but here are no accuracy requirements. This instruction has not been used in any MAP processes.

Another reference document is the 1997 Optical Mission Network Study (ONMS) that looked at the surveillance requirements, SSN optical force structure, deficiencies from the 1997 MAP, and derived several architectures to mitigate deficiencies. In turn the MAP referenced the ONMS solutions in its document.

The 1997 Space Control MAP Space Surveillance deficiencies with proposed generic and specific solutions to mitigate the deficiencies are listed below:

#SC-2 - inadequate forces for complete space situational awareness (deep space metrics-capacity, timeliness)
-- new surveillance techniques (step-stare)
-- improved algorithms
-- new sensors (X-band radars, space-based sensors, CCDs)

#SC-3- inadequate forces for Space Order of Battle (metrics-accuracy; SOI/MPA-capacity/coverage, near earth timeliness, GEO imaging)
-- sensor upgrades (X-band radars, ground-based imager, GEO imager)
-- new SOI techniques (spectral photometry) (why not LADAR)

#SC-7-high cost of O&M (decreasing capability for increasing cost)
-- upgrade sensors
-- new operations (space based sensors)
-- selective automation (small telescopes)

#SC-9-unable to maintain small object catalog (inadequate sensor sensitivity and object correlation)
-- new sensors (S-band radar fence, large aperture optics, LADAR)
-- new algorithms (radar/optical correlation)

#SC-11-lack of processing for unique/high interest orbits (reentries, tethered satellites, multi-day orbits)
-- new sensors (LADAR)
-- new algorithms (multi-day, tethered, decay)

#SC-15-no collision advisories (accuracy, debris tracking)
-- new/upgraded sensors (X-band radar fence, upgrade NAVSPACE fence, small telescopes)

#SC-16-no detection of Near Earth Objects (NEOs) (earth crossing asteroids) (inadequate sensor sensitivity and capacity) - note: this deficiency on the books but not well supported

The table lists the specific surveillance requirements from the SSRD that are associated with high accuracy data, imaging resolution, and collision warning support.

Task	Originator	Requirement	Page
Maint RSO Catalog	NASA R&D	Orbital accuracy .17km –active payload	40
Support Intel	NAIC	For selected payloads, predict position	47
Support Intel/SOB	CIC/NAIC	Imaging – resolution	48
Support Intel	HI-CLASS-Maui	Orbital position .09km radial at 460 km	49
Support Intel			50
Support Negation		Orbital position	56
Support On-Orbit	Owner/Operator	Orbital position	61
Support On-Orbit	NASA	Shuttle/ISS conjunction prediction.3km predict 2 hr	65

Note: There is an updated NASA requirement for debris tracking and collision warning support (and is to be included in the USSPACECOM annex.

WORKING DRAFT

LIST OF LOGISTICS/"NORMALIZATION" DELIVERABLES

To Transition an R&D Project to Operational

Category	Deliverable	Reference	Description
Software	Software Development Plan (SDP)	MIL-STD 498 DID/Template	Presents a sound approach for conducting a software development effort to include new development, modification, reuse, reengineering, maintenance, and all other activities resulting in software products.
	System/Subsystem Specification (SSS)	MIL-STD 498 DID/Template	Covers how the design meets the specifications and be testable; also includes an operational concept on how the system will be used.
	Interface Requirements Specification (IRS)	MIL-STD 498 DID/Template	Provides requirements on interfacing to other CSCIs/systems.
	System Requirements Specification (SRS)	MIL-STD 498 DID/Template	Specifies the requirements for a CSCI and the methods to ensure that each requirement has been met. Note: the IRS contents can be part of the SRS.
	System/Subsystem Description Document (SSDD)	MIL-STD 498 DID/Template	Provides the system-wide design decisions/system architectural design; should also include description of databases, if applicable.
	Software Design Description (SDD)	MIL-STD 498 DID/Template	Covers CSCI requirements, consistent with CSCI-wide design decisions.
	Interface Description Document (IDD)	MIL-STD 498 DID/Template	Describes the interface characteristics of one or more systems, subsystems, Hardware Configuration Items (HWCIs), Computer Software Configuration Items (CSCIs), manual operations, or other system components.
	Software Test Plan (STP) / Software Test Description (STD)	MIL-STD 498 DID/Template	Describes in a combined STP/STD the test plan, preparations, test cases, and test procedures for a sound approach to testing all requirements.
	System Test Results (STR)	MIL-STD 498 DID/Template	Covers all planned test cases; provides results, and shows evidence that the system meets its requirements.
	Software Version Description (SVD)	MIL-STD 498 DID/Template	Identifies the version of each software component (file, unit, CSCI, etc.) delivered and changes, if applicable.
	Software Products Specification (SPS)	MIL-STD 498 DID/Template	References the executable software, source files, and software support information, including "as built" design information and compilation, build, and modification procedures.
	Executable software and source files	N/A	Includes all software necessary for execution. Version exactly matches version that passed testing.
	Software User Manual (SUM)	MIL-STD 498 DID/Template	Describes software installation, input/output, and how to use.
	Computer Operation Manual (COM)	MIL-STD 498 DID/Template	Describes how to operate the computer system that hosts the software.
	Y2K	AF/AFSPC STD Test Cases	Completes Year 2000 assessment and certification that system is Y2K survivable (Y2K compliant is a goal).

LIST OF LOGISTICS/"NORMALIZATION" DELIVERABLES (cont)

To Transition an R&D Project to Operational

Category	Deliverable	Reference	Description
Hardware	Mechanical Design Definition Document		Describes the mechanical design approach to include technical, environmental, or volumetric constraints.
	Mechanical Engineering/Fabrications Drawings Package	Level II	Contains a complete drawing package, from which the hardware can be fabricated without a priori knowledge.
	Optical Engineering Package		Includes optical design definition, ray trace, prescription, sensitivities and tolerances, and performance analysis.
	Electronic Boards Package		Includes design, schematics, parts list, programming instructions, electronic interface control descriptions, and physical board layout.
Operations	System Tech Manual - Operations	MIL-PRF-38314 (USAF)	Describes how to operate the system to meet mission requirements, includes description, functions, procedures (emergency, operating, contingency), limitations.
	System Tech Manual - Corrective Maintenance	MIL-PRF-38314 (USAF)	Describes how to diagnose and complete corrective maintenance on the system.
	Preventive Maintenance Procedures/Inspections	?	Provides the preventive maintenance procedures and inspections to be completed periodically.
Training	Training Plan	Contractor format	Develops plan on how training will be completed for both for Operations and Maintenance (O&M) personnel.
	Training Guide	Contractor format	Develops guide/teaching aid to use during training of O&M personnel.
	Training (Certification)		Completes training (and certification) to operate and/or maintain the system.
Logistics	Special Support Equipment		Identify/provide specialized equipment/tools to operate/maintain system.
	Spares/Parts List		Identified by critical/non-critical (to mission support), long lead time, custom or standard benchstock item.
	Identification Tags		Identifies and tags all system parts, consistent with site identification scheme (MEDL numbers).
	FCA/PCA		Complete functional and physical configuration audits.
Environmental	Environmental Assessment Report		Provides assessment of environmental items.
	AF Form 813		Submits certification of environmental compliance.
	MSDS	Industry STD	Provides on site information on materials.
	Hazardous Materials		Ensure process is in place to identify, manage, and dispose of hazardous materials.
	OSHA review		Ensures compliance.

Note: This list is based on AFSPC and current MSSS Operations, Maintenance, and Support Contract SOW requirements levied on the AFRL/DEBI GEMINI Sensor System at MSSS in 1998 (reference: Feb 1998 GEMINI Operational Transition Plan, jointly signed by AFRL/DEB and AFSPC/DRC).

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Color Photometry of GEO Satellites

AFRL/DEBS Signatures Program

10 November 1998

Presented by

Dr. Mara Payne

Schafer Corp.

Schafer

Agenda

- Space Situational Awareness Overview
- Color Photometry
- SOI In Living Color (SILC) Demonstration
- Summary

Schafer Space Situational Awareness (SSA)

Provide SSA via Space Surveillance Operations (under Space Control Mission)

SS-1 Provide BM/C2 for Space Surveillance Forces

SS-2 Monitor Space - collect, process, and assess data/maintain databases

2.1 Detect/track Resident Space Objects (RSOs)
- Detect new / lost objects
- [illegible]
- Monitor known objects
- Update / manage / disseminate catalog

2.2 Collect data for Space Order of Battle (SOB)
- Detect new foreign launches
- [illegible]
- [illegible]
- [illegible]

2.3 Detect and track Near Earth Objects (NEOs)

SS-3 Analyze data and inform Space Users

3.1 Support Theater Operations
- Provide overflight notification
- Assist theater indications and warning

3.2 Support Space Operations
- Identify safe launch and operating windows
- On-orbit deployments, rendezvous, and operations
- Assist anomaly resolution
- Provide precise orbital data to select owner/operators

3.3 Assist Intelligence Needs
- Collect/process metric and SOI/imaging data

3.4 Assist Treaty Monitoring
- Identify country of origin
- Predict / monitor decays and re-entries
- Detect weapons of mass destruction in space

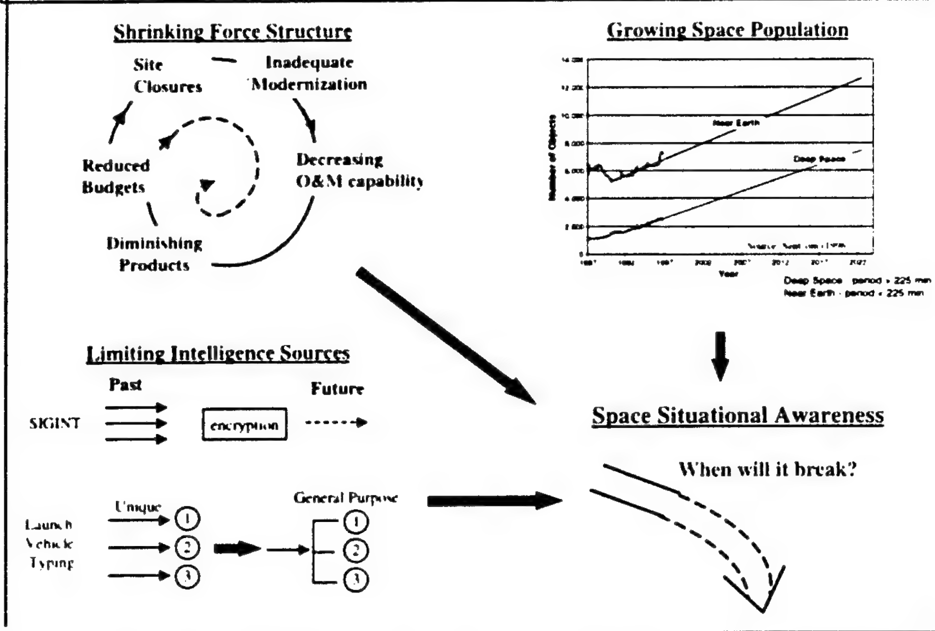
SS-4 Support Counterspace

4.1 Protection
- Detect / warn of threats
- Assist threat and post-event assessment

4.2 Negation
- Identify / track targets
- Assist mission effectiveness assessment

Source: 1997 AFSPC Space Control MAP

Schafer We Are Losing the Ability to Provide SSA



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Surveillance Deficiencies Related to Space Situational Awareness

SC-2 Inadequate forces for complete and timely SSA
- Deep Space Tracking Capacity/Coverage
- GEO Status Change Detection
- Anomaly Resolution

SC-3 Inadequate forces for Space Order of Battle
- GEO Intel data
- SOI/MPA Coverage
- Near Earth Timeliness

SC-7 High Cost O&M for Threat Warning and Space Surveillance
- Automation/Upgrades
- Sensor Calibration
- Atmospheric Characterization

SC-9 Cannot Maintain Small Object Catalog
- Debris precision data

SC-11 Cannot Process Orbits of Unique/Hi-Interest Assets (decaying, tethered, mullti-day, hi- eccentricity satellites)
- Precision data, algorithms

SC-15 No Collision Advisories
- Accurate data predictions with complete space catalog

SC-16 No Agreement or Capability for Detection/Tracking of Near Earth Objects (NEO's)

Source:
1997 AFSPC Space Control MAP

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Potential Solutions for GEO SOI Needs

SOI Needs	Potential Solutions	Payoffs
• ID – Class and type • Status – Is it operational? • Anomaly resolution • Characterization – Primary/secondary missions – Changes – Specific capabilities – Detailed characteristics	• Improve photometric data collection and exploitation – brightness – color – polarimetry – space-based • Exploit NMD X-band radars to extend coverage – Range profiles – Imaging (rotating objects) • Ground based optical imaging (e.g. GLINT) • Space Based optical • Extend GEO radar imaging with SB fly-by	• More accurate status determination • Potential for identification and orientation assessment • Improved anomaly resolution and damage assessment • Improved GEO coverage • Detailed mission/capability characterization

Source: Optical Network Mission Study (ONMS), 1997

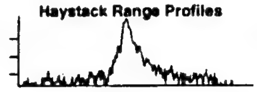
Schafer — Current SOI Capabilities in GEO

• Coverage limited to Haystack viewing

ID

Inadequate

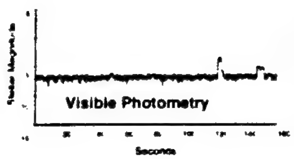
Haystack Range Profiles

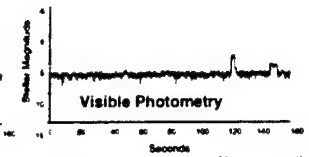


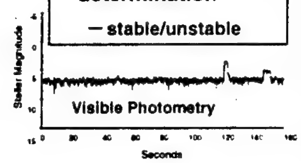
Inadequate

• Limited ID & status determination
— stable/unstable

Status







Characterization

None

Haystack Images

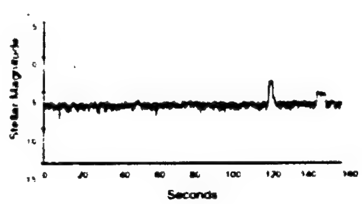
• No imaging of earth stable satellites (>70% of SOB)

None

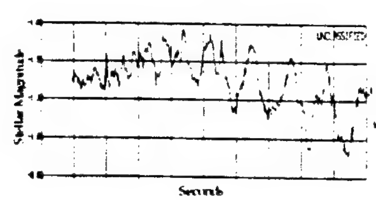
Source: Optical Network Mission Study (ONMS), 1997

Schafer — Current Optical Capabilities in GEO

Stable



Unstable



Or is it?

- Some features on payload or panels cause brightness fluctuations.
- Low confidence in status determination using this data.
- Status determination limited to stable vs. unstable.
- Single visible bandpass.
- Magnitudes not well calibrated.

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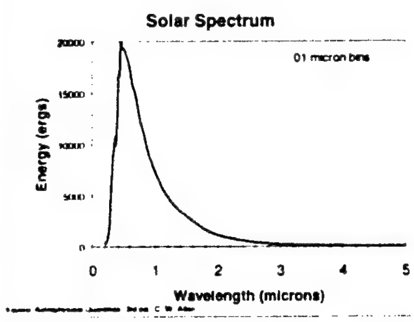
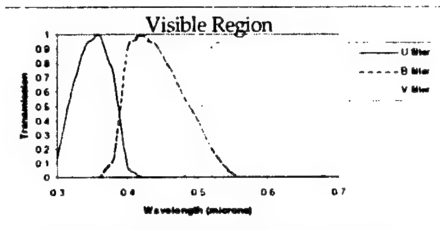
Color Photometry Technique

- Can we get more information from color (spectrum)?
- a.k.a. Multi-Spectral Photometry
- Origins: Astronomical Photometry
- Definition: Measurement of the apparent brightnesses of an object in various wavelength bands in the optical or infrared regions of the spectrum





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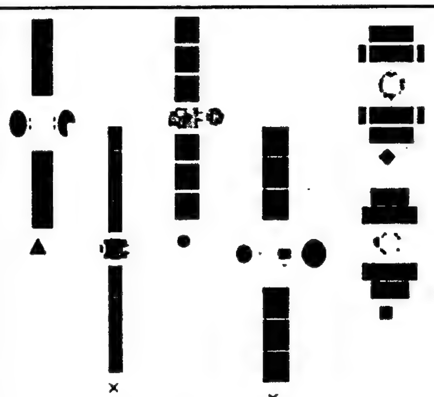
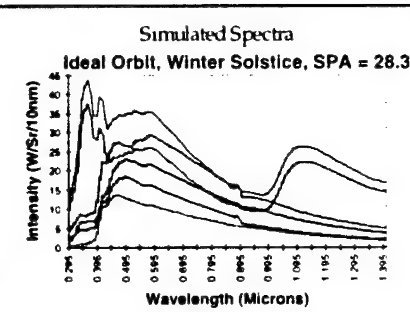
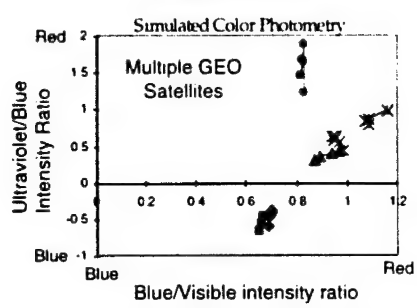
Recent AFRL Research





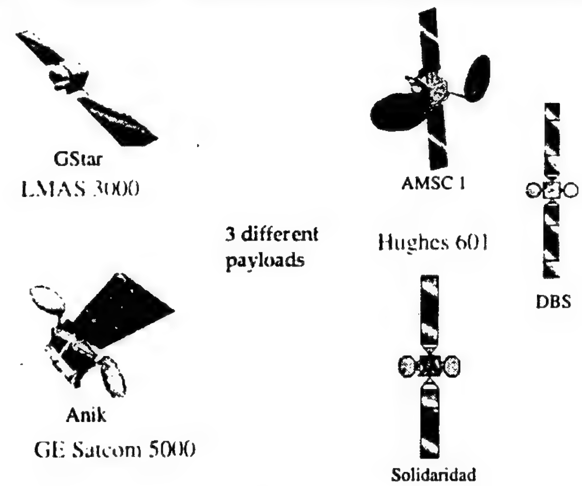


- TASAT simulations provided clues that color photometry may facilitate identification of GEOs.
- Simulated spectra showed different features that corresponded to class of satellite.
- Color photometry created from these spectra showed even more distinguishing characteristics.
- Observations were needed to prove these data could be obtained.

Schafer — Capilla Peak Observations

10 satellites

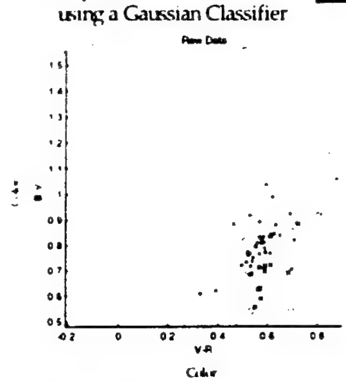
Solidaridad 1 - 22911
Solidaridad 2 - 23313
Anik E1 - 21726
Anik E2 - 21222
DBS 1 - 22930
DBS 2 - 23192
DBS 3 - 23598
AMSC 1 - 23553
Gstar 4 - 20946
Spacenet 4 - 21227



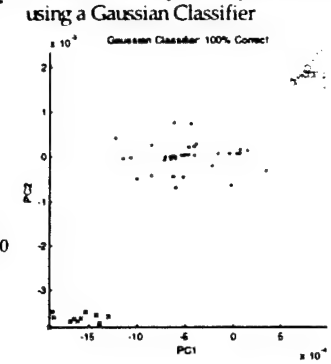
- Dr. Steven Gregory, IPA, astronomer at University of New Mexico
- Investigated these satellites in Fall 1996 - Summer 1997
- Current data set: late Spring 1998 - end of FY 99

Schafer — Current AFRL Experiments

Capilla Peak Observations using a Gaussian Classifier → Results of Principal Component Analysis using a Gaussian Classifier



Hughes 601
LMAS 3000
GE Satcom 5000



Probability of Correct ID = 79.26 %

Probability of Correct ID = 100 %

- Color photometry data on 10 different satellites with 3 different payload types. Some of which are in a cluster.
- Pattern recognition algorithms have aided discrimination of payloads.

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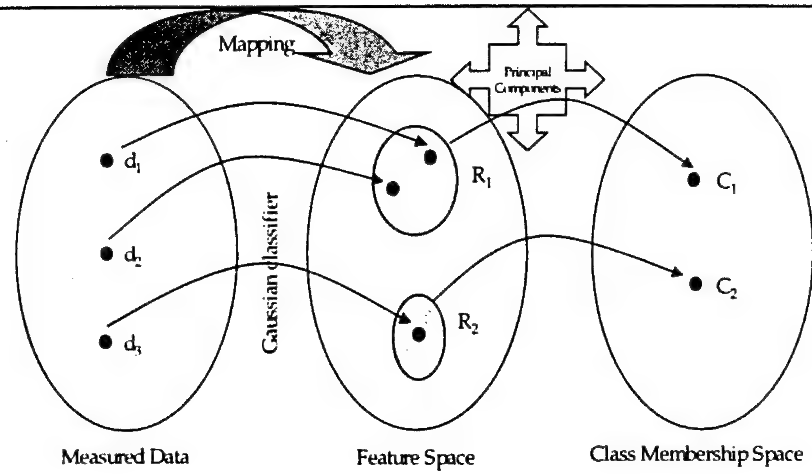
Pattern recognition (PR) Algorithms



- PR can be defined as an information reduction, information mapping, or information labeling process.
- The mapping reflects our choice of measurement system.
- In realistic cases, the feature space regions overlap by some amount.

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Current Status of Color Photometry

- Payoffs from color photometry technique
  - Contribute to identification (permits exploitation)
  - Improved status determination
    - Potential for orientation detection
    - Better estimates of ops use
  - Help reduce mistagging
- AFRL/DEBS Signature Program plans limited color photometry data collection on GEOS over FY99.
- AFRL/DEPA GEODSS Multi-Spectral Data (GMSD) program plans to finish analysis of color photometry data collected from GEODSS - Socorro.
- These efforts insufficient to bring technique to operational readiness.
  - NEED MORE DATA
- To exploit differences in signatures to optimize photometric technique (filters, phase angles, algorithm development).

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SILC

- Objective:
  - Demonstrate the capability of multi-spectral (color) photometry to identify deep space satellites during cross tagging situations and multi-spectral photometry's capability to evaluate the operational status of the Space Order of Battle (SOB).
- Benefits:
  - Collaboration between 3 branches of AFRL (DEBI, DEBS, DEPA)
    - » Resources
    - » Expertise
    - » Timeliness
  - Synergy
    - » Shared data, algorithms, and lessons-learned would facilitate development of color photometry technique.
  - SILC will address operational transition of this technique. Diverse AFRL programs will not.

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Summary

- Known SOI deficiency for GEO satellites.
- Color photometry is potentially a solution for mistags and an additional capability for ops status.
- Color photometry sponsored by AFRL Directed Energy Directorate.
- SWC/Space Battlelab SILC plans to demonstrate operational utility.

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Date: 12 November 98

From: Dr. Mara Payne, Ms. Linda Crawford

To: Mr. Stan Czyzak, AFRL/DEBS

Cc: Dr. Dave Voelz, Ms. Lee Kann, AFRL/DEBS
Lt. Darrell Phillipson, AFRL/DEPA
Mr. Paul Kervin, AFRL/DEBI
Dr. Darryl Sanchez, UPR

Re: Trip Report, Color Photometry Briefing at Combined Intelligence Center (CIC), Peterson AFB, CO, 10 November 98

Dr. Payne provided a briefing to AFSPC and USSPACECOM on the AFRL Color Photometry efforts, concentrating on the recent data collected at the Capilla Peak observatory, and how the technique relates to the Space Warfare Center/Space Battlelab (SWC/SB) SOI in Living Color (SILC) initiative (see attachment 1). SWC/SB also had a summary briefing of SILC (see attachment 2) with a primary objective of soliciting user support. Recently SWC/SB completed a "rack and stack" of the SB initiatives and SILC is on the "bubble" as to whether it gets funded.

The following were in attendance:

USSPACECOM/J2V - Col Gendron
USSPACECOM/J2F – Col DeLoughery (CIC Cmdr), Maj Lutz, TSgt Fields
SWC/SB – Col Bivins (SB Cmdr), LtCol Wright (Dep Cmdr), Capt Trimble (SILC POC)
AFSPC/DRCS – LtCol Smith
AFSPC/DOI – Mr. Pease, Capt Sears (Intel section for Ops)
ICACS
Schafer Corp. – Mr. Boykin, Ms. Crawford, Dr. Payne

Dr. Payne presented her briefing, which included how the color photometry technique supports some of the Space Situational Awareness deficiencies, as identified by the 1997 Space Control Map. She showed that the limited set of collected data was highly successful in identifying the type of payload. Maj Lutz during the briefing continually stressed the need for such a technique and stated that the number of mistagged deep space objects has increased to 15% of which mistagged GEO objects were approximately 34%.

LtCol Smith stated that he favors the completion of the SILC demonstration and sees the results dovetailing into the GEODSS CCD Upgrade program, for which funding has been allocated starting in FY00. If successful, he felt that color photometry requirements could be included in the A-Specification of the GEODSS CCD Upgrade program with a low cost impact. LtCol Smith said that DRCS would coordinate with the GEODSS CCD Upgrade program acquisition agency, ESC (Boston). The color filter wheels are already on the GEODSS telescopes, but currently have clear glass in them.

This schedule is consistent with Col Bivins' desire to complete the demonstration within 6 months, with results completed in 9-12 months. There was a concern about the time period (FY99), since this demonstration was planned to be a joint effort between SWC/SB and AFRL/DE (DEBI, DEBS, DEPA) with DEBI FY99 funds.

However, LtCol Smith suggested that the SILC demonstration be changed to use the larger aperture telescopes at Maui (the 1.2m, 0.8m, and 3.6m) versus the RAVEN small telescopes. He was concerned that the capabilities of the small telescopes would not be sufficient to demonstrate the technique successfully.

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He stated that AFSPC would support the allocation of those larger telescopes for the demonstration. This suggested re-direction needs to be discussed with Mr. Kervin, AFRL/DEBI (Maui). He was also concerned that the use of RAVEN would confuse the SILC initiative with the SOA initiative completed last year. Space Surveillance Network Optical Augmentation (SOA) was the small telescope augmentation Battlelab initiative with AFRL/DEBI.

Another discussion was held on the analysis tool to process the data. The CIC representatives stated that they wanted a tool that processed the data quickly, was semi-automated (in making assessments), was logistically supportable (documentation, releases), and was a separate program from IDASS/IDPS, but could be hosted on the same Silicon Graphics (SGI) (IRIX operating system) platform. Eventually, they could see a utility of being able to use these data in IDASS for S&T analysis, but were concerned that IDASS took too long to set up and execute. LtCol Smith suggested that CIC document their user requirements for the color photometry analysis tool.

With unanimous support from the attendees (and especially from the CIC), Col Bivins directed that a team be assembled to develop a briefing for the Jan 99 General Officers Advisory Group (GOAG) that is to include the operational benefit of color photometry/SILC and the cost of implementing color photometry techniques on the operational GEODSS system. Capt Trimble was established as the POC for contacting the organizations, assigning tasks, and collecting the information. He plans on having a telecom/VTC next week to kick off this effort.[1]

Dr. Payne was asked to provide technical support, specifically how will the operational procedures at GEODSS change in collecting the color photometry data, and how long will it take per track. A concern was raised that if the time increased substantially, the time available for metrics data collection on GEODSS would decrease. TSgt Fields stated that the E-O systems are tasked for SOI tracks monthly as follows: Socorro – 70; Maui – 70, Diego Garcia – 170, TOS (Spain) – 100. Also needed is the number of signatures required to populate an operational database (to include different types of payloads and phase angles).

SWC/SB will be sending a letter to AFSPC/DOY asking for the specific user needs and deficiencies that this technique would mitigate. Note: After the meeting, Dr. Payne and Ms Crawford provided copies of the briefings and a synopsis of the discussion to Maj Brandstrom, AFSPC/DOYO.

In summary, it was apparent that this color photometry technique, developed at AFRL, has strong support with AFSPC and USSPACECOM users. This is an excellent opportunity to have an AFRL R&D project become operational. We recommend that AFRL/DEBS, AFRL/DEBI, and AFRL/DEPA strongly support the SILC team efforts and the users' suggestions for modifying the demonstration.

We are available to support every aspect of this demonstration, from providing technical information for the briefing and demonstration preparations, collecting and analyzing the data during the demonstration, to supporting the development of a quick response color photometry analysis tool.

Atch 1: Color Photometry of GEO Satellites
Atch 2: Space Battlelab Proposed Initiative: Space Object Identification in Living Color

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[1] Capt Trimble scheduled a VTC at 1300 on November 17, 1998.

Color Photometry Data Collection Procedure

1. **Preparation and Set-Up (Sunset/Dusk) – Total time = 30 minutes**
   Telescope and computer prep – no special needs –
      The telescope is assumed to be up and running, focused, and boresighted. We spend approximately 2 hours converting the 2 line element sets to right ascension/declination coordinates that are used by the telescope using SATTRACK.
   Sky flat-field frames through all filters (CCD calibration) – 15 minutes
      This procedure must be performed during twilight if the sky is used. Alternative: dome flat-fielding could be performed, but a uniformly-illuminated screen in the dome would have to be constructed for each telescope.
   Bias frames (CCD calibration) - 15 minutes

2. **Observing Time (Stellar)**
   Once-A-Month – Fully calibrated night – Total time = 30 minutes (for a 6 hour night)
      Flux calibration star – all filters (B,V,R,I) – observe 1 hour apart– 1 second exposure – Time per ob = 5 minutes
   Regular night – Total time = 15 minutes (for a 6-8 hour night)
      Flux calibration star – all filters (B,V,R,I) – observe 4 hours apart– 1 second exposure – Time per ob = 5 minutes

3. **Observing Time (Satellites)**
   All filters – Average time per ob = 3 minutes
   Average time between obs (to find satellite) = 2.3 minutes

WORKING DRAFT

COLOR PHOTOMETRY DATA EXPLOITATION TOOL (CPDET)

Requirements/Deliverables To Transition an R&D Project to Operational Use

Category	Deliverable	Reference	Description
Performance– Interopera-bility and Standards	Interface Control Document (ICD)	AFSPCI 60-102 Draft Technical Requirements Document (TRD) for Sensor Exploitation Tools (5 Dec 97)	1 – Uses Space Surveillance Astrodynamic Standards 2 –Can ingest, parse, display, and output Flexible Image Transport System (FITS) formatted data (there may be improvements to FITS, such as filter information) 3 – Can format the data/file to be compatible for input to other data exploitation tools (such as IDPS and IDASS). 4 – Has the capability to interface to the existing networks and communications links for automated data input and output
Performance-Data Display and Interface		Draft Dec 97 TRD	1 – Has simultaneous data display; has capability to plot more than four main bands and the ability to interactively select which signatures to display at any one time (each FITS file can have four or more separate signatures). 2 – Allows user to selectively display all, some, or none of the signatures independently, and perform some elementary measurements, such as allowing the user to select start and stop times and report the time (or pixels) between the user selected points; report the data value as the user moves a cursor along the signature, zoom control, etc.
Performance-Data Processing		Draft Dec 97 TRD	1 – Has the capability to input photometric color magnitudes versus phase angle (or time) curve. 2 – Has the capability to examine/provide combination of color photometry for the color measurements and phase angle-based measurements for the brightness relationship 3 – Provides the ability for automated statistical probability determination of satellite/payload identification.
Performance-Data Management		Draft Dec 97 TRD	1 - Capable of performing database comparisons (i.e., compare new data with existing data); allows searches and sorts on various features of the different data sets (e.g., look at all signatures over time for one satellite under certain astronomical conditions)
Software	Computer & Software Resources	Draft Dec 97 TRD MIL-STD 498 (or replacement STD)	1 - Stand-alone tool, hosted on Silicon Graphics platform running under UNIX operating system (IRIX) 2 – No proprietary code, except COTS. 3 – Developed code and database using established programming standards and maintained under a configuration management tool. 4 – Modular design to allow for future tool enhancements, such as additional types of data input (i.e., radiometric) and data analysis (i.e., spectral analysis of time series signature).
	User Interface, Displays, Output	HSI STD	1 – Compliant with latest Human Systems Integration (HSI) standard

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WORKING DRAFT

COLOR PHOTOMETRY DATA EXPLOITATION TOOL (CPDET) (cont)

Requirements/Deliverables To Transition an R&D Project to Operational Use

Category	Deliverable	Reference	Description
Software	Requirements and Design Documentation	MIL-STD 498 (or replacement STD) DID/Template	1 - System/Subsystem Specification (SSS)- How the design meets the specifications and be testable; also includes an operational concept on how the system will be used. 2 – System Requirements Specification (SRS) or Interface Requirements Specification (IRS) - Provides requirements on interfacing to other CSCIs/systems (can include in SSS) 3 - System/Subsystem Description Document (SSDD) - Provides the system-wide design decisions/system architectural design; also includes description of databases. 4 - Software Design Description (SDD) – Covers the CSCI level design and decisions (can include in SSDD) 5 - Interface Description Document (IDD) - Describes the interface characteristics of one or more systems, subsystems, Hardware Configuration Items, Computer Software Configuration Items (CSCIs), manual operations, or other system components.
	Software Testing Documentation (note: can replace or be subset of DT&E documentation)	MIL-STD 498 (or replacement STD) DID/Template	1 - Software Test Plan (STP) / Software Test Description (STD) - Describes the test plan, preparations, test cases, and test procedures for testing all requirements. 2 - System Test Results (STR) - Covers all planned test cases; provides results, and shows that the system meets its requirements.
	Software Description	MIL-STD 498 (or replacement STD) DID/Template	1 - Software Version Description (SVD) or Version Release Package (VRP) - Identifies the version of each software component (file, unit, CSCI, etc.) delivered and changes, if applicable. 2 - Software Products Specification (SPS) - References the executable software, source files, and software support information, including "as built" design information and compilation, build, and modification procedures.
	Executable software and source files	AFSPC-AFMC MOA - Software Normalization, 16 Feb 93	Includes all software necessary for execution. Version exactly matches version that passed testing and will be under configuration control/management.
	Operations Documentation	MIL-STD 498 (or replacement STD) DID/Template	1 - Software User Manual (SUM) - Describes software installation, input/output, database structure, how to use the tool, guidelines for analysis of results, error messages, and normal processing notifications. 2 - Computer Operation Manual (COM) - Describes how to operate the computer system that hosts the tool. 3 – Mathematical/Algorithmic Description Document

WORKING DRAFT

COLOR PHOTOMETRY DATA EXPLOITATION TOOL (CPDET) (cont)

Requirements/Deliverables To Transition an R&D Project to Operational Use

Category	Deliverable	Reference	Description
Training	Training Plan	Developer format	Develops plan on how training will be completed for both for Operations and Maintenance (O&M) personnel.
	Training Guide	Developer format	Develops guide/teaching aid to use during training of O&M personnel.
	Initial Training	Developer format	Completes training to operate and/or maintain the system. Training shall include all command and control functions, system familiarization, procedures and low level system malfunction analysis, data processing, data editing, data validation, classification control, and data transmission.
Logistics	Special Support Equipment		Identify/provide specialized equipment/tools (software or hardware) to operate/maintain system (if applicable)
	Spares/Parts List		Identified by critical/non-critical (to mission support), long lead time, custom or standard benchstock item.
	Maintenance Agreements	Draft Dec 97 TRD	For delivered software and hardware, support agreement (s) in place and effective for at least one year after certification
	Functional and Physical Configuration Audit (FCA/PCA)	AFSPC-AFMC MOA	Verifies that the tool functions and that it matches the physical description detailed in the documentation. The results shall be included in the SVD/VRP.
Security	Accreditation	DOD DIR & STD 5200.28	Adequate security and access controls as per criteria established by user and in directive/standard.
Testing	System Testing (DT&E)		1 - DT&E Plan/Procedures - Describes the test plan, preparations, test cases, and test procedures for testing all system-level requirements (from the specification). 2 – DT&E Report - Covers all planned test cases; provides results, and shows that the system meets its requirements.
	Y2K Testing	AF/AFSPC STD Test Cases	Completes Year 2000 assessment and certification that system is Y2K survivable (Y2K compliant is a goal).
	Operational Utility Evaluation (OUE) Testing		1 - OUE Plan/Procedures - Describes the test plan, preparations, test cases, and test procedures for testing OUE. (to be completed by user) 2 - OUE Report - Covers all planned test cases; provides results, and shows that the system meets OUE. (to be completed by user). Note: The developing agency supports OUE by providing the results from DT&E and providing technical support during OUE conduct.
Certification	Certification	Space and Missile Payload Assessment System (SMPAS)	Based on OUE results, successfully complete certification criteria and added to the operational SMPAS.

WORKING DRAFT

COLOR PHOTOMETRY DATA EXPLOITATION TOOL (CPDET)

Rough Order of Magnitude (ROM) Cost

Reference: Draft CPDET Requirements/Deliverables to Transition to Operational Use, 8 Dec 98

Performance/Deliverable Summary	Assumptions	LOE (hrs)	Est. Cost
Operational Color Photometry Data Exploitation Tool Development **1. Input/Output** - input/output ICD-defined data formats, files, messages (SSN, other tools – IDPS, IDASS) - interface to existing networks/links for automatic data input/output **2. Data Display and Interface** - Select signatures to display, up to four plots, display data value/time, zoom, etc. **3. Data Processing** - with input of photometric color magnitudes vs. phase angle (or time), develop brightness relationship - provide the ability for automated statistical probability determination of satellite/payload identification **4. Data/Database Management** - perform comparisons, searches, sorts, database utilities **5. Software** - compatible to SMPAS, SGI platform/IRIX - use programming standards - maintained under CM tool - modular design for future tool enhancements - HSI user interface standards	Mathematical algorithms and prototype tool developed during SILC time period Computer and software purchased for development, testing, configuration management (CM), and maintenance GEODSS CCD Upgrade program includes support of color photometry data collection (anticipated changes include ops procedures/calibration, reduction of raw data on site to derive four color magnitudes/time change in message header/possible format	Scientist 6 - 500 Sys Anlyt 4 – 1000 Prgmr 3 - 1000	Labor -$195K H/W - $20K S/W (operating system, DBMS, Development Tools, CM Tool) - $30K
Logistics **1. Provide Special Support S/W & H/W Tools** **2. Develop Spares/Parts List** **3. Establish Maintenance Agreements (S/W & H/W)** **4. Conduct FCA/PCA**	One year of H/W and S/W COTS maintenance support Assumes COTS, no critical spares/no spares purchased	Prgmr 3 – 100	Agreements - $10K Labor - $6K
Security Accreditation Support	Customer is responsible; developer only provides support and ensures tool meets security directives	Sys Anlyt 4 – 100	Labor - $8K

11

WORKING DRAFT

COLOR PHOTOMETRY DATA EXPLOITATION TOOL (CPDET) (CONT)

Rough Order of Magnitude (ROM) Cost

Reference: Draft CPDET Requirements/Deliverables to Transition to Operational Use, 8 Dec 98

Performance/Deliverable Summary	Assumptions	LOE (hrs)	Est. Cost
Software Process and Documentation **1. Conduct PDR/CDR** **2. Complete documentation** a - System/Subsystem Specification (SSS) b – System Requirements Specification (SRS) (includes Interface Requirements Specification (IRS)) c - System/Subsystem Description Document (SSDD) d - Software Design Description (SDD) e - Interface Description Document (IDD) f - Software Test Plan (STP) / Software Test Description (STD) g - System Test Results (STR) h - Software Version Description (SVD) or Version Release Package (VRP) i - Software Products Specification (SPS) j - Software User Manual (SUM) k - Computer Operation Manual (COM) l - Mathematical/Algorithmic Description Document m - DT&E Plan/Procedures n - DT&E Report	Tailored MIL-STD 498 formats and process, with government approval Some documents combined, with government approval (e.g., STP/STD and DT&E; SRS and IRS)	Scientist 6 – 100 Sys Anlyt 4 – 500 Tech/Prgr 1 - 1000 Admin Spt - 750	Labor - $97K
Testing/Certification **1. Conduct CSCI/System Testing** **2. Conduct DT&E (includes Y2K)** **3. Support OUE Support** **4. Support Ops S/W Certification**	Customer to complete OUE and S/W certification developer to provide support, as required	Sys Anlyt 4 – 100 Prgmr 3 - 200 Tech/Prgr 1 - 200	Labor - $25K
Training **1. Develop Training Plan and Guide** **2. Conduct Initial Training**	Training includes O&M areas, will be on-the-job training, and will use the SUM/COM as training materials	Sys Anlyt 4 – 100 Prgmr 3 - 150 Tech/Prgr 1 - 150 Admin Spt - 100	Labor - $23K
Technical Meetings/Management/Misc. Support	As required	Scientist 6 – 100 Sys Anlyt 4 – 300 Prgmr 3 – 350 Admin Spt – 200	Labor - $50K Travel - $20K Expendables - $10K
TOTALS			**Labor - $390K** **Other - $90K** **Total - $480K**

WORKING DRAFT

COLOR PHOTOMETRY DATA EXPLOITATION TOOL (CPDET) (CONT)

Rough Order of Magnitude (ROM) Cost

Reference: Draft CPDET Requirements/Deliverables to Transition to Operational Use, 8 Dec 98

Labor costs derived from GSA Contract categories and rates

Category	Rate/hour
Technical Specialist/Admin Support/Programmer 1 – High School/Associate degree	$27
System Engineer/Programmer 3 – Technical BS degree with 2 years experience	$59
System Engineer/Analyst 4 – Technical BS (MS preferred) degree with 5 years experience	$76
System Engineer/Analyst/Scientist 6 – Technical MS/PhD degree with 10 years experience	$120

Space Situational Awareness

Essential for Military Operations

1 Dec 98

Air Force Research Laboratory

Surveillance Technologies Branch

AFRL/DEBS
Stan Czyzak
DSN 246-4845

Background

Military use of all classes of space systems is increasing

- US/Allied
- Potential Adversary

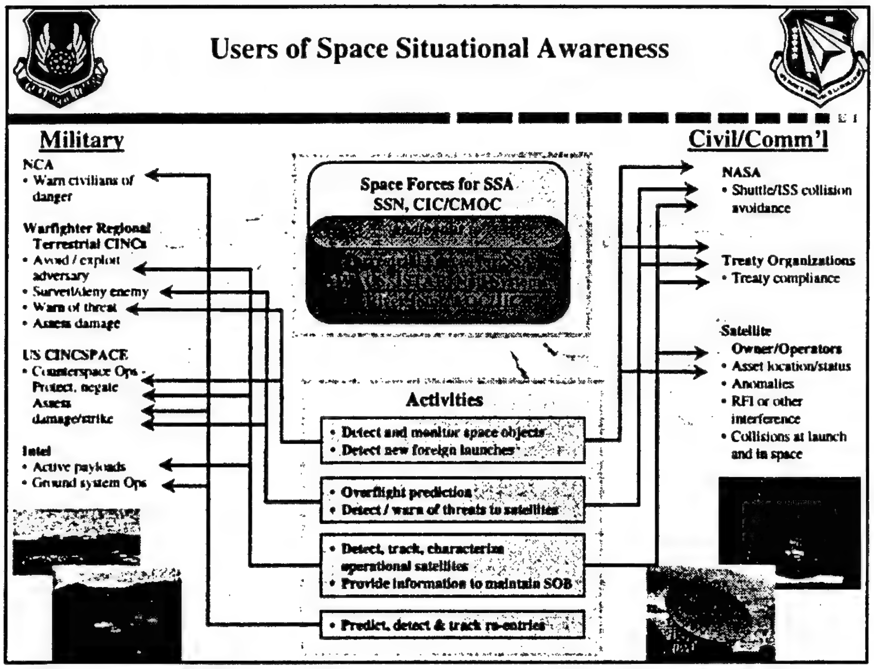
U.S. economic interests in space growing rapidly

Infrastructure for maintaining control of space is shrinking

Strong leadership support of Space Situational Awareness by:

- National Space Policy
  - "Modernize Space Surveillance..to detect...characterize threat to US space systems...and protection of military activities"
- USCINCSPACE
  - "Space surveillance is the 'first order of business' at USSPACECOM"
  - "Global partnerships" leveraged with commercial for Integrated Space "Traffic Control" and "Accident Investigation" to protect "Space Lanes for Commerce"

Space Situational Awareness Modernization Needed



Users of Space Situational Awareness
Military
NCA
• Warn civilians of danger
Warfighter Regional Terrestrial CINCs
• Avoid / exploit adversary
• Surveil/deny enemy
• Warn of threat
• Assess damage
US CINCSPACE
• Counterspace Ops - Protect, negate Assess damage/strike
Intel
• Active payloads
• Ground system Ops
Space Forces for SSA
SSN, CIC/CMOC
Activities
• Detect and monitor space objects
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Civil/Comm'l
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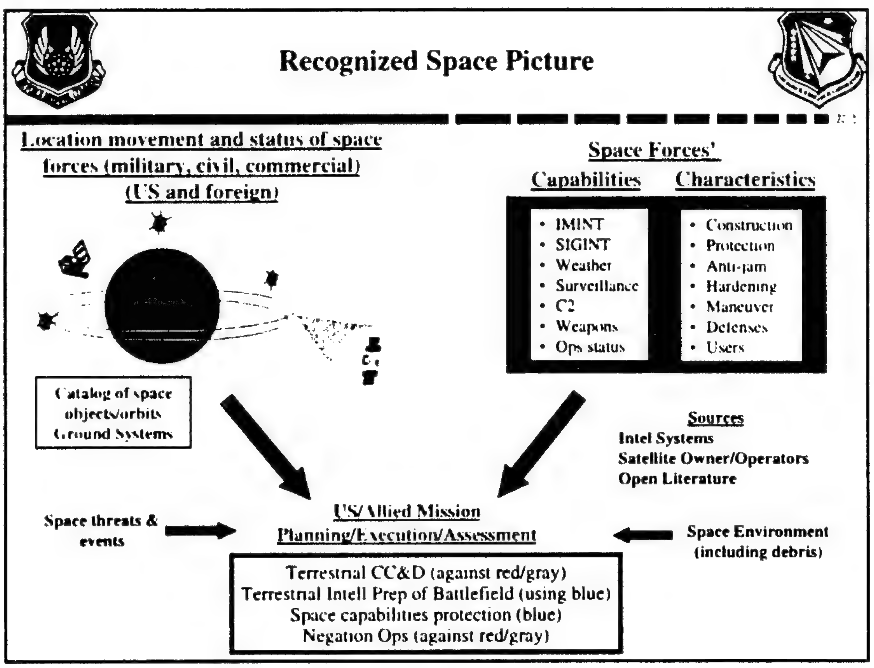

Recognized Space Picture
Location movement and status of space forces (military, civil, commercial) (US and foreign)
Catalog of space objects/orbits Ground Systems
Space Forces'
Capabilities
• IMINT
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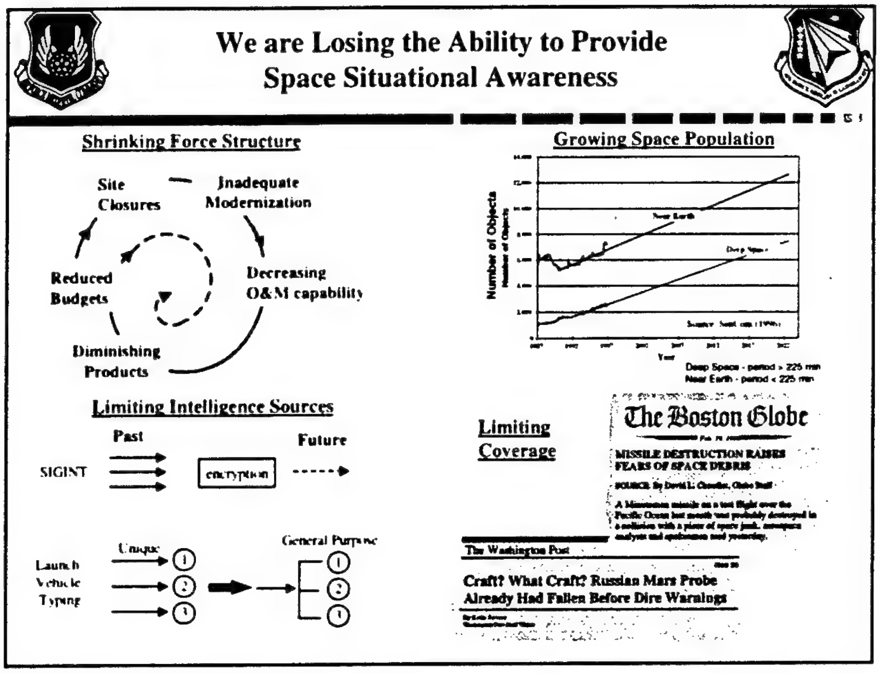
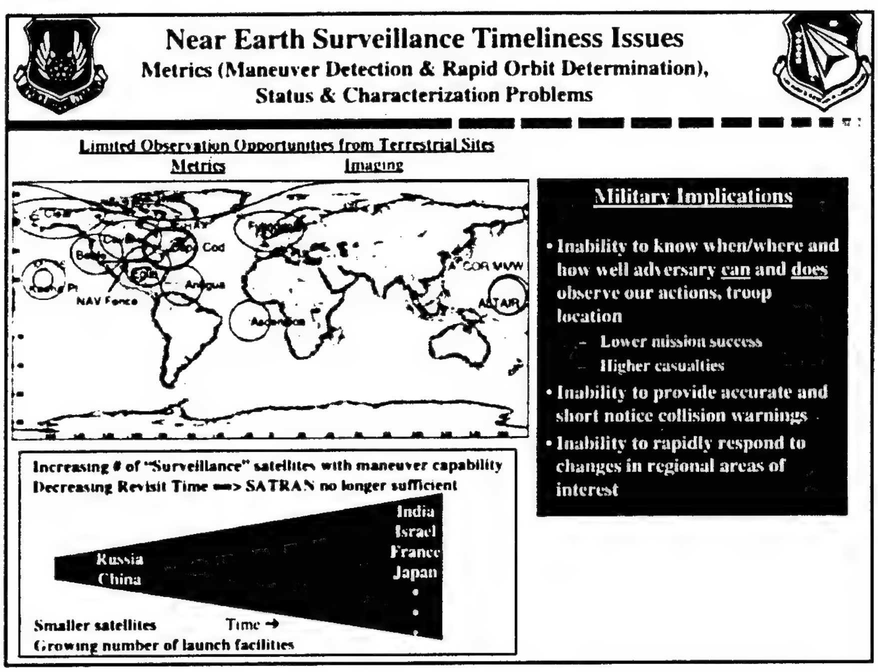

We are Losing the Ability to Provide
Space Situational Awareness
Shrinking Force Structure
Site Closures
Inadequate Modernization
Decreasing O&M capability
Diminishing Products
Reduced Budgets
Growing Space Population
Number of Objects
Near Earth
Deep Space
Year
Deep Space - period > 225 min
Near Earth - period < 225 min
Limiting Intelligence Sources
Past
Future
SIGINT
encryption
Unique
General Purpose
Launch Vehicle Typing
Limiting Coverage
The Boston Globe
MISSILE DESTRUCTION RAISES FEARS OF SPACE DEBRIS
The Washington Post
Craft? What Craft? Russian Mars Probe Already Had Fallen Before Dire Warnings


Near Earth Surveillance Timeliness Issues
Metrics (Maneuver Detection & Rapid Orbit Determination), Status & Characterization Problems
Limited Observation Opportunities from Terrestrial Sites
Metrics
Imaging
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NAV Fence
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Increasing # of "Surveillance" satellites with maneuver capability
Decreasing Revisit Time ==> SATRAN no longer sufficient
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India
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France
Japan
Smaller satellites
Time →
Growing number of launch facilities
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• Inability to know when/where and how well adversary can and does observe our actions, troop location
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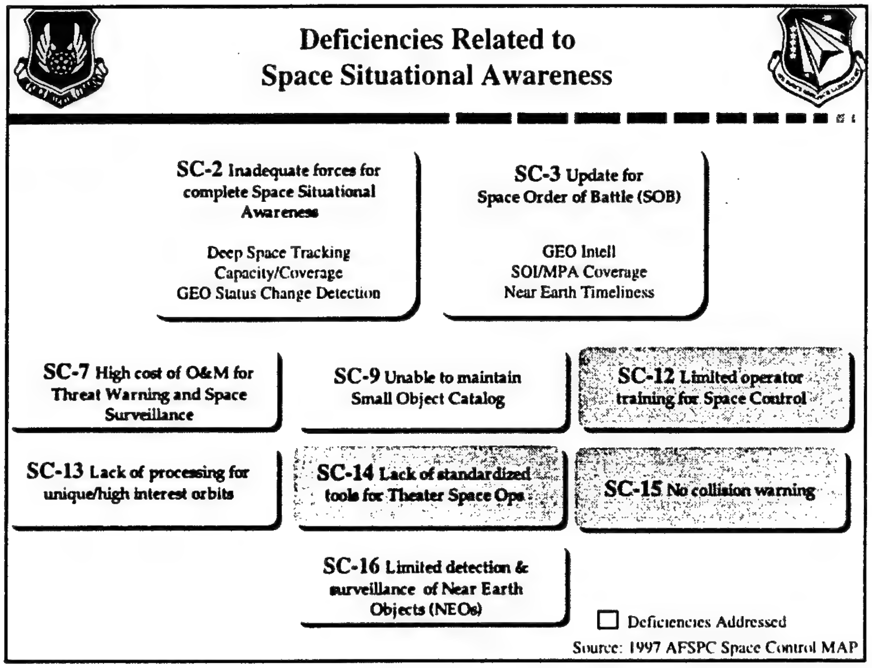
Deficiencies Related to
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SC-2 Inadequate forces for complete Space Situational Awareness
Deep Space Tracking
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GEO Status Change Detection
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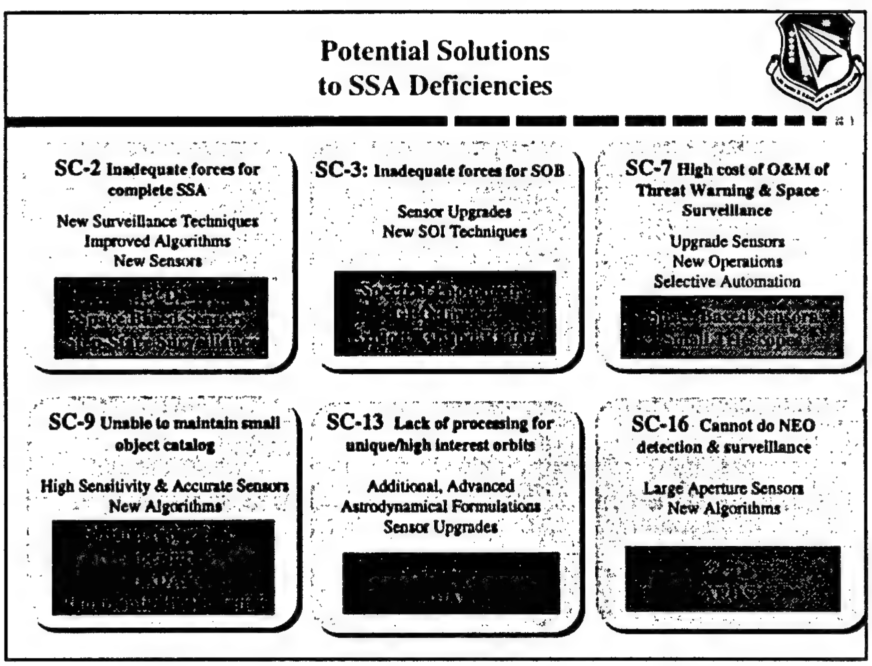
GEO Intell
SOI/MPA Coverage
Near Earth Timeliness
SC-7 High cost of O&M for Threat Warning and Space Surveillance
SC-9 Unable to maintain Small Object Catalog
SC-12 Limited operator training for Space Control
SC-13 Lack of processing for unique/high interest orbits
SC-14 Lack of standardized tools for Theater Space Ops
SC-15 No collision warning
SC-16 Limited detection & surveillance of Near Earth Objects (NEOs)
Deficiencies Addressed
Source: 1997 AFSPC Space Control MAP


Potential Solutions
to SSA Deficiencies
SC-2 Inadequate forces for complete SSA
New Surveillance Techniques
Improved Algorithms
New Sensors
SC-3: Inadequate forces for SOB
Sensor Upgrades
New SOI Techniques
SC-7 High cost of O&M of Threat Warning & Space Surveillance
Upgrade Sensors
New Operations
Selective Automation
SC-9 Unable to maintain small object catalog
High Sensitivity & Accurate Sensors
New Algorithms
SC-13 Lack of processing for unique/high interest orbits
Additional, Advanced Astrodynamical Formulations
Sensor Upgrades
SC-16 Cannot do NEO detection & surveillance
Large Aperture Sensors
New Algorithms

Summary

- SSA critical to warfighter
- Current/programmed force structure inadequate to do the job
- Potential solutions have been identified
- Investment decisions required

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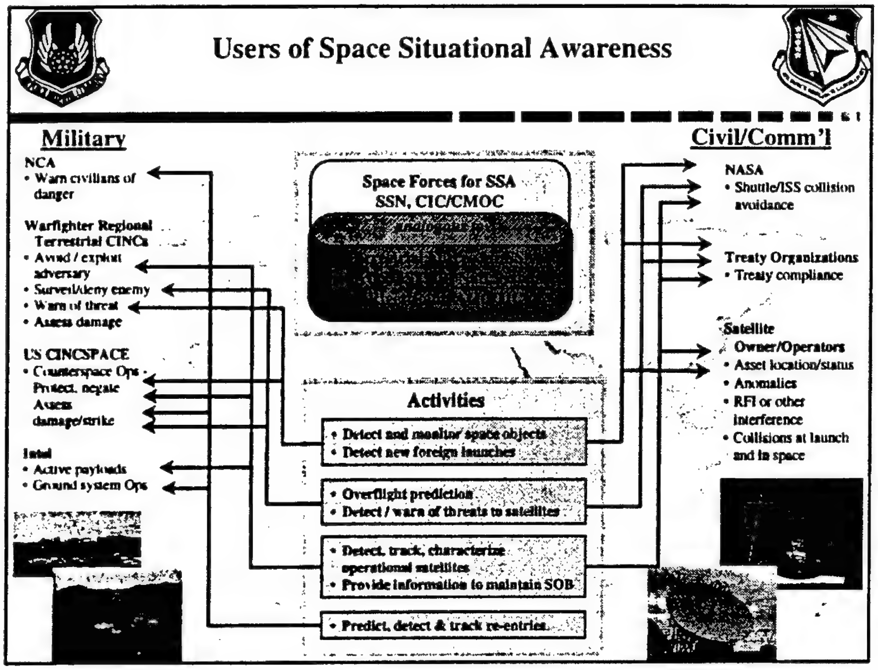
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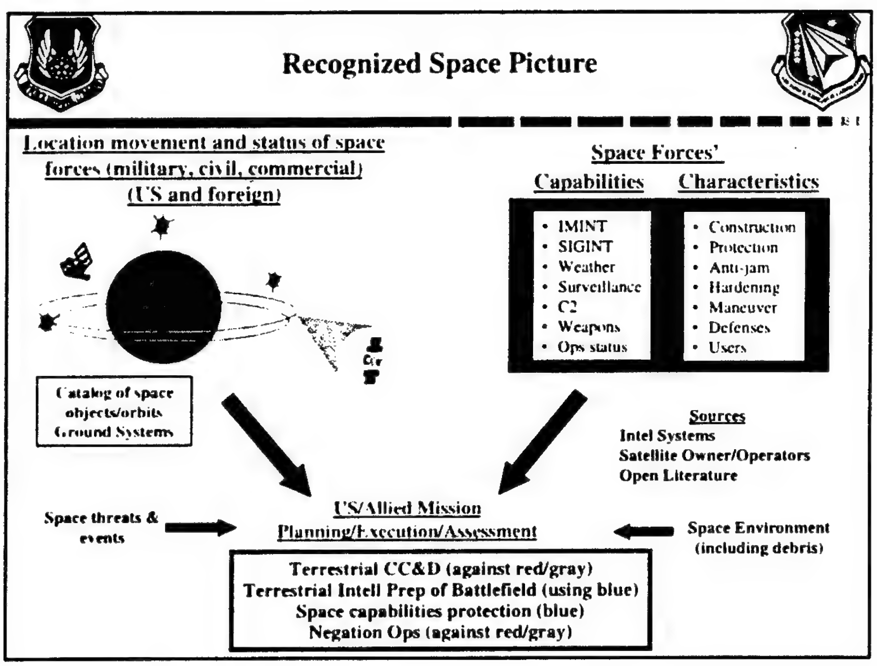
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Terrestrial CC&D (against red/gray)
Terrestrial Intell Prep of Battlefield (using blue)
Space capabilities protection (blue)
Negation Ops (against red/gray)

Challenges to Maintaining the Recognized Space Picture

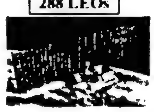
- Growth in space object population
- Increased complexity of space payloads - multiple payloads/spacecraft
- Source limitations to determine the characteristics, capabilities and ops status
- Military use of commercial space capabilities--owned/leased
- Small space objects and manned presence in space
- Shrinking force structure and site closures
- Aging (1970s) equipment with limited replacements
- Diversity in launch platforms- numbers/locations, ground/sea/air launch

Growing Satellite Population

Low Earth Orbit (LEO)/Middle Earth Orbit (MEO)

Iridium
66 LEOs

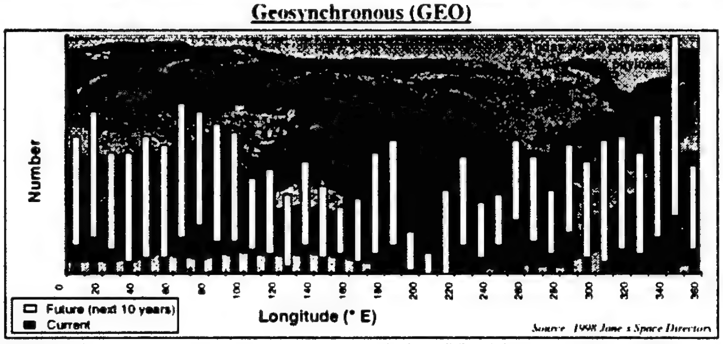
Teledesic
288 LEOs



ICO
10 MEOs

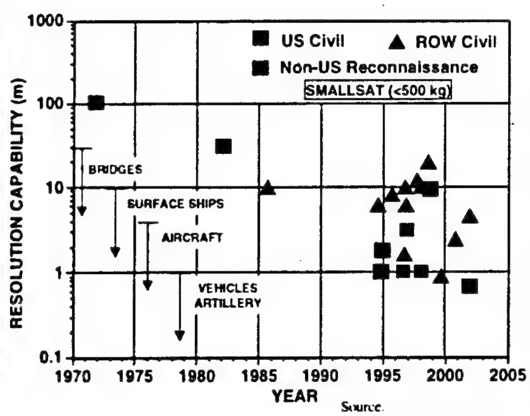
Globalstar
48 LEOs

Geosynchronous (GEO)



Growing Capability of Active Payload Operations

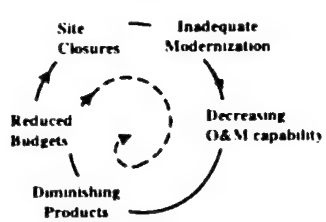
- Growth in number and capability of foreign and commercial ISR systems
  - Optical, radar, SIGINT, ELINT
- Ability to image far from the nadir ground direction
  - "Where is it looking now?"
- Multiple, independently directed, narrow comm beams
- Orbit adjustments and maneuver



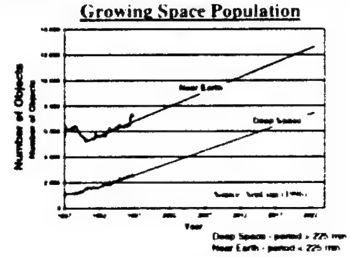
Source:
1998 Jane's Space Directory

We are Losing the Ability to Provide Space Situational Awareness

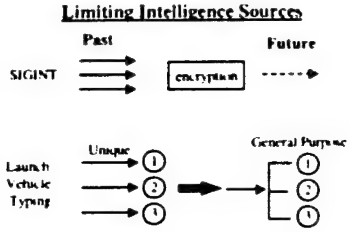
Shrinking Force Structure



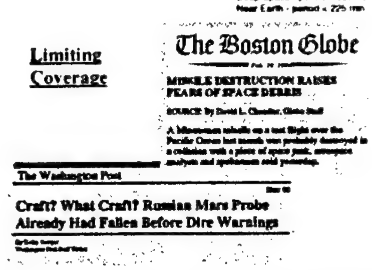
Growing Space Population



Limiting Intelligence Sources



Limiting Coverage



Deficiencies Related to Space Situational Awareness

SC-2 Inadequate forces for complete Space Situational Awareness

Deep Space Tracking
Capacity/Coverage
GEO Status Change Detection

SC-3 Update for Space Order of Battle (SOB)

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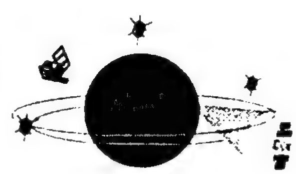
☐ Deficiencies Addressed

Source: 1997 AFSPC Space Control MAP

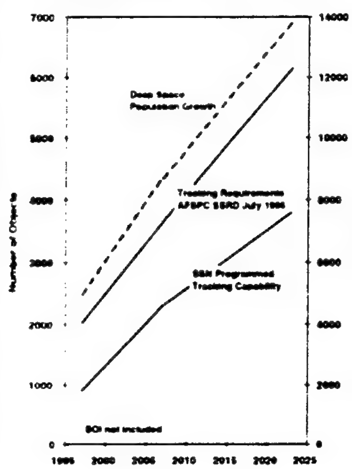
Issues and Solutions

- **Deep Space**
  - Metric tracking coverage and capacity
  - Status and change detection capability
  - Characterization
- **Near Earth**
  - Timeliness - metrics and status
  - Characterization capability



Inadequate Deep Space Metric Tracking Coverage and Capacity

Deep Space Population Growing



Military Implications

- Inability to monitor communications
  - C^2 } Frequent complaints by users
  - Intel data
- Increasing potential for collision
- Uncertainty in adversary coverage
  - Comm for C^2
  - Missile detection
  - Intel collection

Potential Solutions

- Update tracking by object type/class
- Do smart surveillance (Step-Stare, Tasking)
- Add sensors (CCDs, small telescopes, exclusion zone sensors, global coverage)

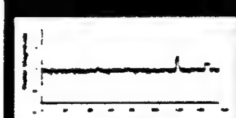
Payoffs

- Fewer "lost" objects
  - Current location for intelligence exploitation
  - Less time "wasted" searching for lost objects
  - More complete catalog
  - Lower collision potential

Inadequate GEO Status and Change Detection Capability

Military Implications

- Range Profiles coverage limited to Haystack viewing
- Limited ID & Status
  - visible photometry (stable /unstable)



- No imaging of earth stable satellites (70% of SOB)

Potential Solutions

- Improve photometric data collection and exploitation
  - brightness
  - color/spectral
  - polarimetry
  - space-based (SB)
- Exploit NMD X-band radars to extend coverage
  - Range profiles
  - Imaging (rotating objects)
- Develop ground-based (GB) optical imaging (e.g., GLINT)
- Add SB optical capability
- Extend GEO GB radar imaging with SB fly-by

Payoffs

- More accurate status/ID determination
  - Reduces mistagging
- Potential for identification & orientation assessment
- Improved GEO coverage
- Improved anomaly resolution and damage assessment
- Detailed mission/capability characterization

Color Photometry Technique
Near Term Solution

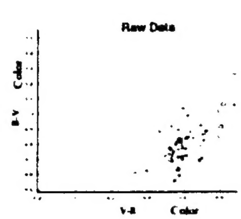
- **Measures the apparent brightness of an object in various wavelength bands (optical or infrared) of the spectrum**
  - — Facilitates identification of GEO payload types
  - — Coupled with pattern recognition algorithm

Solidaridad
Hughes 601

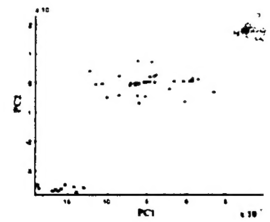
GStar
LMAS 3000

Anik
GE Satcom 5000

Observations using a Gaussian Classifier → Results of Principal Component Analysis using a Gaussian Classifier

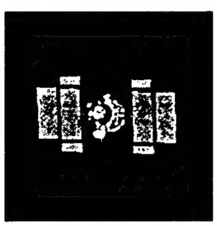


Probability of Correct ID = 79 %



Probability of Correct ID = 99 %

Limited GEO Intell Capability
Imaging for ID, Status, Characterization and Anomaly Resolution



Today →

Potential Solutions

Future Imaging
- GB optical
- SB optical
- GB/SB radar(bistatic)

Military Implications

- Inability to know ID, status & mission with sufficient confidence levels (insufficient image resolution

Payoffs

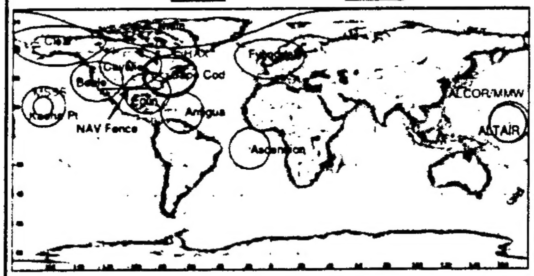
- Accurate Status Determination
  - Aware of military use
  - Timely exploitation
- Mission/capability characterization
  - Military utility known
    - Can take actions to avoid
  - Secondary missions identified
    - Historically a weak area
- Anomaly resolution/damage assess
  - Support problem identification and resolution - e.g., MILSTAR
  - Assess damage and potentially determine origin - natural, etc.

Near Earth Surveillance Timeliness Issues

Metrics (Maneuver Detection & Rapid Orbit Determination), Status & Characterization Problems

Limited Observation Opportunities from Terrestrial Sites

Metrics | Imaging



Increasing # of "Surveillance" satellites with maneuver capability

Decreasing Revisit Time ==> SATRAN no longer sufficient

Smaller satellites | Time →

Growing number of launch facilities

Military Implications

- Inability to know when/where and how well adversary can and does observe our actions, troop location
  - Lower mission success
  - Higher casualties
- Inability to provide accurate and short notice collision warnings
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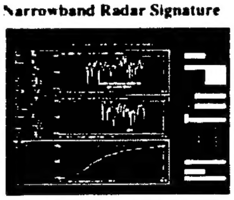
Current LEO Characterization Capabilities

Radar

WB Radar Image

Narrowband Radar Signature



Military Implications

- ID limited
  - Inadequate size and shape information for small satellites (< 1 m)
- Status determination limited by radar coverage
  - No theater coverage
- Inadequate characterization
  - Resolution inadequate for detailed characterization
- Limited anomaly resolution for small satellites
- Insufficient timeliness

Potential Solutions

- Optical imaging assets - Maui, Starfire
- Daytime imaging
- Advanced imaging algorithms

Optical

Maui Image

Shuttle
1.6 m telescope
raw image

post processed
image using
advanced algorithm

Starfire Image

3.5 m telescope
raw image

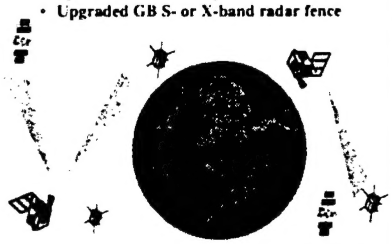
model representation

Key Question: When & how well will forces be imaged

Near Earth Timeliness Issues
Potential Solutions

Metric

- Space-based electro-optic surveillance
- Upgraded GB S- or X-band radar fence

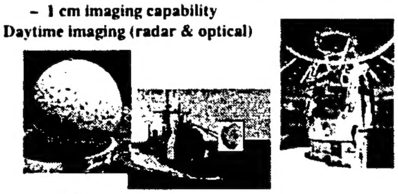


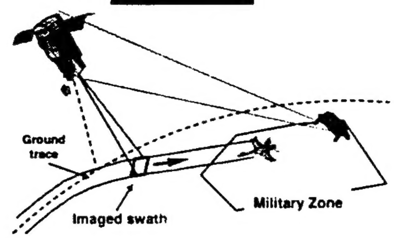
Payoffs

- Current knowledge of foreign recce spacecraft locations
  - Low risk of exposure of critical military operations
- Decreased probability of collision
- Better tip-off to new spacecraft/capabilities
  - Limit earlier problems

Status & Characterization

- Theater Satellite Imaging Radars with fixed imaging radars (Haystack, GBR-P, HAX, ALCOR, MMW)
  - 1 cm imaging capability
- Daytime imaging (radar & optical)





Potential Solutions
to SSA Deficiencies

SC-2 Inadequate forces for complete SSA

New Surveillance Techniques
Improved Algorithms
New Sensors

[illegible]

SC-3: Inadequate forces for SOB

Sensor Upgrades
New SOI Techniques

[illegible]

SC-7 High cost of O&M of Threat Warning & Space Surveillance

Upgrade Sensors
New Operations
Selective Automation

[illegible]

SC-9 Unable to maintain small object catalog

High Sensitivity & Accurate Sensors
New Algorithms

[illegible]

SC-13 Lack of processing for unique/high interest orbits

Additional, Advanced Astrodynamical Formulations
Sensor Upgrades

[illegible]

SC-16 Cannot do NEO detection & surveillance

Large Aperture Sensors
New Algorithms

[illegible]

Summary

- SSA critical to warfighter
- Current/programmed force structure inadequate to do the job
- Potential solutions have been identified
- Investment decisions required